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High school students' 21st-century learning skills in organic chemistry group learning

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ABSTRACT

Children with 21st-century learning abilities thrive in today's globalized world, underscoring the importance of early skill development by both schools and parents. This study aims to evaluate high school students' grasp of organic chemistry in relation to critical thinking, creativity, communication, and collaboration skills. Conducted with 15 groups of grade 12 students in science-mathematics, the research employed a mixed-methods approach, combining written surveys and observations. Statistical tools such as averages, standard deviations, and correlation coefficients were utilized for data analysis, followed by specific statistical tests to ensure validity and significance. Correlation analysis was used to examine the relationships between each 21st-century learning skill. Findings indicate that in organic chemistry, students hone critical thinking through data evaluation, and problem-solving, while fostering creativity in molecule synthesis and solution-finding. Effective communication fosters collaboration and teamwork, essential for achieving common goals. Average scores from writing surveys for critical thinking, creativity, and communication were 1.62, 1.65, and 1.68, respectively, with collaboration evaluated through observation scoring 2.03. Notably, a significant positive correlation was found between each skill, indicating that enhancing one skill often leads to improvements in the others. This highlights the importance of a holistic approach to developing 21st-century educational abilities.

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1. INTRODUCTION

The 21st-century skills, encompassing knowledge, practical skills, career readiness, habits, and character qualities, are essential for success in today's world [1]. These abilities are necessary for navigating a complex and evolving world, with a particular emphasis on strong analytical abilities and congenial dispositions [2]. Educational reforms seek to equip students with the skills to tackle modern challenges, emphasizing research, problem-solving, critical thinking, and collaboration [3]–[5].

Common names for 21st-century learning capabilities include the 4Cs: i) applying information from different fields and disciplines and viewing issues from a novel angle are key components of critical thinking; ii) the ability to produce a variety of ideas, alter them in novel ways, and form novel connections in order to seek inventive solutions to complete issues, are all components of creative thinking; iii) the capacity to convey concepts, ideas, and solutions to another individual is known as communication; and iv) the practice of uniting intelligence, ability, and expertise to accomplish a shared goal is called collaboration [6], [7]. These skills facilitate learning, which makes them necessary for academic achievement both in school and after [8]. It is imperative that classrooms, schools, and districts all across the country fully integrate these abilities in order to produce citizens and workers who are adequately prepared for the twenty-first century.

Learning consists of two basic components: learning alone utilizing one's knowledge and comprehension, and learning socially or in a group with a range of people. Group learning involves individuals collaboratively solving problems, creating products, and deriving meaning, with each person learning autonomously and from others' learning methods [9]. As they consider other points of view and listen to others, they must provide an explanation for and defense of their positions. Participants in group learning face emotional and social difficulties. By doing this, the students break free from solely depending on that text or an authority person and start to develop their own original conceptual framework. Students also engage in active peer conversations, present and defend ideas, discuss different points of view, and research different conceptual frameworks [10].

Chemistry is a branch of science that studies substances, including their composition, characteristics, and changes in energy as a result of laws and natural processes [11]. Integrating chemistry with educational principles forms the basis of chemical education. Chemistry, with its abstract principles, often poses challenges for students to relate to real-life situations [12]. Therefore, chemistry education research aims to enhance learning activities that help students grasp chemical concepts and create rewarding educational experiences [13]. This research focuses on developing effective teaching methods, curricula, and assessment strategies. Through this, students not only gain strong analytical, communication, and problem-solving skills but also develop social responsibility by evaluating the environmental impact of chemical processes and seeking to minimize harm. Recognizing the global implications, chemistry education promotes collaborative solutions for sustainable outcomes, enabling students to apply their knowledge and skills in real-world contexts [14].

Chemistry education plays a vital role in equipping students with global competencies, often referred to as 21st-century skills, enabling them to compete effectively in a rapidly changing world [15]. The 4Cs–critical thinking, creativity, communication, and collaboration-that make up the 21st-century learning capacities model can also be seen as a chemistry competence model, closely aligning with chemistry epistemology. Critical thinking in organic chemistry involves analyzing complex chemical reactions, understanding reaction mechanisms, and evaluating experimental data to draw conclusions. Creativity is essential when students propose novel synthesis routes or design experiments to solve chemical problems. Communication skills are crucial for effectively presenting research findings or explaining chemical concepts to peers, which is especially important given chemistry's broad implications across various vocations and industries [16]. Collaboration is fostered through group work on laboratory experiments or projects, where students learn to work together to achieve common goals in understanding organic chemistry concepts. This integration ensures that chemistry education not only imparts essential knowledge but also develops the critical 21st-century skills necessary for students to thrive in their future careers and contribute to solving global challenges.

The curriculum of educational institutions is focused on producing a generation of people who are productive, creative, inventive, and effective by integrating attitudes, talents, and knowledge with life skills. Nonetheless, the majority of educators concur that these abilities must be taught in schools as part of the common core curriculum and learning activities [17]. To prepare students for a better life in the globalization era, the study has made several efforts to enhance the essential skills they need to thrive in a rapidly evolving global environment [18], [19]. The study was conducted to explore the integration of the 4Cs model into organic chemistry education, aiming to enhance students' holistic skill development alongside subject-specific knowledge. Since 21st-century skills are essential for success in today's complex and evolving world, with educational reforms emphasizing the importance of these skills in tackling modern challenges. To achieve this, students engaged in group learning settings where they collaboratively participated in laboratory experiments, discussions, and projects. Emphasis was placed on promoting collaboration, critical thinking, creativity, and communication skills throughout these activities, fostering a deeper understanding and application of organic chemistry concepts while preparing students to navigate real-world challenges effectively.

2. METHOD

2.1. Research design and participants

This study was quasi-experimental in nature, combining both quantitative and qualitative research methods to conduct in-depth case studies with high school students. The research involved 86 grade 12 students, aged 18–19, who were enrolled in the science-mathematics program during the second semester of the 2022 academic year. The students were divided into four classrooms, with 41 females and 45 males in total. For the study, which took place between December 2022 and February 2023, a sample of 80 students (40 females and 40 males) was selected from three of the grade 12 classrooms using a non-probability purposive sampling technique [20]. One class, known as the gifted class, which included one female and five males, was excluded from the study due to differences in the curriculum.

In each classroom, students were further divided into smaller groups of 5-6 individuals, based on the academic backgrounds, particularly their previous coursework in chemistry. These groups were categorized as good (1 person), pretty good (1-2 persons), average (1 person), and weak (2 persons) in terms of academic performance. A total of 15 groups from classes 1 (31 participants, 6 groups), 2 (33 individuals, 6 groups), and 3 (16 participants, 3 groups) comprised the study's sample.

2.2. School curriculums

This course lasts eight weeks, each week is divided into two days of 100 and 50 minutes (total 150 minutes). Before starting the lab activities, the students attended lectures to learn about each topic and the relevant data. All students were required to participate in two laboratory activities, each preceded by a lecture on the respective topic: alkane, alkene, and alkene reactions with Br_2 and $KMnO_4$ in week 3, and carboxylic acid and alcohol reactions in week 6. The teacher instructed the students to spend a week planning their laboratory experiment. Each student created a detailed experiment plan that was clear to everyone in their group. These plans included drawings and labels for the chemicals and their volumes, avoiding long sentences. During the laboratory week, each group selected the best plan from their members to guide their experiment. This process was supported by information provided in the textbook received to students at the start of the semester, which covers all lectures and experiments. Following the completion of the lab, each group was given a skills evaluation test with 30 minutes to discuss their answers together and write them down for assessment. In this course, each group of students was tested twice for critical thinking, creativity, and communication related to laboratory content. Collaboration skills were assessed during the inquiry and experimentation phases. After completing the laboratory work, each group submitted their answers along with the best plan they had selected.

2.3. Instruments

The chemistry instructor and the first author of this study worked together to develop the questions in Figure 1 using the curriculum of the school. These questions focused on critical thinking (item 1), creativity (item 2), and communication skills (item 3). Chemistry experts authorized the questions for review and assessment. The authors found that written-answer questions can be created faster and more easily than multiple-choice questions and they also provide a better assessment of a student's knowledge and abilities [21]. The main advantage of written-answer questions is that they allow for a deeper and more comprehensive evaluation of a student's understanding and skills. These questions require students to express their thoughts, explain their reasoning, and show their knowledge in more detail, leading to a better measurement of their learning compared to multiple-choice questions. In addition, the students' abilities were evaluated using an observation sheet for collaborative skills.

2.4. Data collection

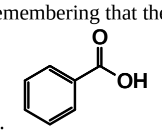
A written answer question is used to gather information on communication, creativity, and critical thinking; Tables 1, 2, and 3 show the test's scoring criteria correspondingly. Additionally, creativity and communication were evaluated using the laboratory plan, with criteria detailed in Tables 2 and 3. These rubrics part of a survey to evaluate how well the activity in Figure 1 matches the 4Cs. Additionally, the rubric in Table 4 is used to collect data on collaborative skills through observation. The teacher/assessor assessed the student's critical thinking skills using an evaluation rubric based on Table 1. They used the frameworks from Zulfaneti *et al.* [22] to modify this rubric. The goal of the evaluation procedure was to give a thorough appraisal of the student's critical thinking abilities.

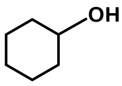
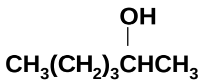
Furthermore, the students gathered information, and the 'creativity' of their findings was evaluated utilizing the criteria listed in Table 2. The frameworks developed by Piedra *et al.* [23] were used to modify this rubric. Based on the predetermined criteria, the assessment sought to determine the pupils' level of creativity. This rubric also evaluates the creativity of the experimental plans selected by all group members.

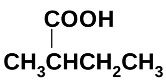
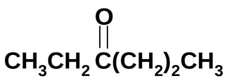
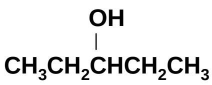
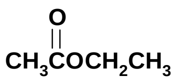
The students were expected to converse with their team members regarding their communication abilities (C3) to collect and select the best reason to write the answer question. The teacher evaluated the written data by assigning based on the rubric outlined in Table 3. This rubric was modified by using the frameworks of Ramachandiran *et al.* [24]. In addition, this rubric evaluates the effectiveness of the experimental plans in helping members understand and follow the correct procedures.

1) If the teacher wants students to redo an experiment studying how carboxylic acid and alcohol interact. But they found that the substance they used is mixed with many chemicals and comes in a container that's not labelled clearly. They need to explain what different substances might be in the container. What chemicals do students think could have been used in this experiment? (Choose only 4 options)
1. It is a combustible material. Since carbon dioxide and water are the end products of an exothermic process, there is no soot or smoke.
2. It is a polar molecule that dissolves in water because it has a hydroxyl group.
3. It is a material that may dissolve in non-polar solvents but is insoluble in water. It is a gas, liquid, and solid.
4. Because of its many states and double bonds, this material has a very high chemical reactivity.
5. It is a material that can be found in fruits and vegetables. When carbon is added, it becomes less soluble in water and has a mild corrosive effect.
6. Because it has a carboxyl group, it has a greater boiling point than alcohol with the same carbon count.
7. It is a non-polar molecule with low melting and boiling points, is highly combustible, and is insoluble in water.
8. It is a material having an alkoxy carbonyl group that is mostly odorous and insoluble in water. As the amount of carbon atoms increases, the water solute drops.
Please explain the reasons in detail.

2) The pupils selected one of the aforementioned possibilities. What structure do you believe the compounds should have? Remembering that the compounds you select can only be used once, match the compounds.

A. 
B. **$CH_3(CH_2)_5OH$** C. **$CH_3(CH_2)_2O(CH_2)_2CH_3$** D. **$CH_3(CH_2)_2CH(CH_3)COOH$**

E. 
F. **$CHO(CH_2)_2CH_3$** G. **$HOOC(CH_2)_4CH_3$** H. 

I. 
J. 
K. 
L. 

1)……+……., 2) ……+……., 3) ……+……. and 4) ……+…….
Kindly list each compound's structure and provide an explanation.

3) In the match mentioned above, write the ester compound's IUPAC name, which is created when an alcohol and a carboxylic acid combine to form a precursor.
……+…….=…………………………………………………………………………………..
……+…….=…………………………………………………………………………………..
……+…….=…………………………………………………………………………………..
……+…….=…………………………………………………………………………………..
Please explain the principle of writing a simple outline.

Figure 1. Example of the organic chemistry test

Table 1. Student critical thinking skills test scoring criteria

Critical thinking elements	Score	Descriptors
Determine assumptions	3	Be able to accurately select all the choices.
	2	Be able to select the correct choices, but there are not all that are correct yet.
	1	Be able to select the correct choices, but there is only one that is correct.
	0	Unable to select the choices correct at all.
Formulate the main problem	3	Be able to accurately describe the properties of alcohol and carboxylic acid.
	2	Be able to describe the properties of alcohol and carboxylic acid, but there are not all that are correct yet.
	1	Be able to describe the properties of alcohol and carboxylic acid, but not all of them are correct yet.
	0	Unable to describe the properties of alcohol and carboxylic acid at all.
Discover information, ideas, and definitions to aid with problem solving	3	Be able to accurately describe the information, ideas, or definitions by giving examples in the laboratory.
	2	Be able to describe the information, ideas, or definitions by giving examples in the laboratory, but not all of them are correct yet.
	1	Be able to describe the information, ideas, or definitions by giving examples in the laboratory, but there is only one that is correct.
	0	Unable to describe the information, ideas, or definitions by giving examples in the laboratory at all.
Evaluate the relevant arguments when solving problems	3	Be able to accurately describe all the pertinent arguments.
	2	Be able to describe the pertinent arguments, but there are not any yet that are exact.
	1	Be able to describe the pertinent arguments, but have only one exact one.
	0	Unable to accurately describe the pertinent arguments at all.

Table 2. The evaluation tool for students' creative abilities

Creative elements	Score	Descriptors
Product	3	Be able to accurately select all the choices.
	2	Be able to select the correct choices, but there are not all that are correct yet.
	1	Be able to select the correct choices, but there is only one that is correct.
	0	Unable to select the choices correctly at all.
Content	3	Be able to accurately describe the functional groups of alcohol and carboxylic acid.
	2	Be able to describe functional groups of alcohol and carboxylic acid, but there are not all that are correct yet.
	1	Be able to describe functional groups of alcohol and carboxylic acid, but there is only one that is correct.
	0	Unable to describe the functional groups of alcohol and carboxylic acid.
Connection	3	Be able to accurately write the structure of all the products.
	2	Be able to write the structure of the products, but not all of them are correct yet.
	1	Be able to write the structure of the products, but there is only one that is correct.
	0	Unable to write down the structure of all the products.
Reflection	3	Be able to accurately describe other structures that are not alcohol and carboxylic acid.
	2	Be able to describe other structures that are not alcohol and carboxylic acid, but not all that are correct yet.
	1	Be able to describe other structures that are not alcohol and carboxylic acid, but there is only one that is correct.
	0	Unable to describe any other structure that is not alcohol and carboxylic acid.
Originality	3	Shows strong originality, design includes unique ideas, and work is clear and easy to understand.
(Laboratory plan)	2	Demonstrates moderate originality, design has recognizable ideas, and work is adequately clear.
	1	Shows limited originality, design has few unique ideas, and work is somewhat unclear.
	0	Demonstrates little to no originality, design lacks unique ideas, and work is poorly understood.

Table 3. The rubric for student's communication skills

Communication elements	Score	Descriptors
Purpose	3	Be able to spell all the names of products accurately.
	2	Be able to spell the names of products, but not all of them are correct yet.
	1	Be able to spell the names of products, but there is only one that is correct.
	0	Unable to spell the names of all products.
Content	3	Be able to correctly write the principles of ester names in the IUPAC system.
	2	Be able to write the principles of ester names in the IUPAC system, but not all of them are correct yet.
	1	Be able to write the principles of ester names in the IUPAC system, but there is only one that is correct.
	0	Unable to write the principles of ester names in the IUPAC system.
Organization	3	Be able to accurately organize and write the structure of all products.
(Writing survey)	2	Be able to organize and write the structure of products, but not all of them are correct yet.
	1	Be able to organize and write the structure of products, but there is only one that is correct.
	0	Be unable to organize and write the structure of all products.
Organization	3	The plan is obvious, well-organized, and easy to understand, effectively communicating data.
(Laboratory plan)	2	The plan is moderately clear and organized, adequately communicating data.
	1	The plan is somewhat unclear and lacks organization, making it difficult to understand the data.
	0	The plan is poorly presented, with significant clarity and organization issues, failing to communicate data.

Table 4. The rubric of student's collaboration skills

Collaboration elements	Score	Descriptors
Responsibility	4	Make the most of the full period to stay on course and produce the required results. To finish an activity, each participant must contribute.
	3	Professionals make up the bulk of long-term team members, and teamwork works. Nearly every assignment given to the team was completed by every member.
	2	Completing the task becomes difficult when a team is working together because it is not always possible for everyone to contribute or fulfil this responsibility.
	1	Not very helpful. Because everyone wants to complete tasks in their own unique style and give advice to the other team members on how to do them, the team is not focusing on the assignment.
Respect one another	4	It required a team to listen to each other's views and describe them respectfully.
	3	When they engaged and listened, the majority of team members showed respect.
	2	It can be difficult for certain team members to value the opinions of others.
	1	No one on the team wants to talk to anyone else or argue with someone else.
Compromise	4	Each member of the team can adjust as needed to achieve common goals.
	3	Members of the group usually work together to complete tasks.
	2	Several group members work together to complete tasks.
	1	The group members do not cooperate to do the task in hand.
Shared accountability	4	Every team member puts in their best effort and finishes the assigned work.
	3	Most of the team members are working on the project at hand.
	2	Many team members were involved in group initiatives.
	1	Not every member of the team takes part in cooperative projects.

Teachers observe student activities and collect data. Five assistant instructors, who are in their last year of student teaching, participate as observers. To ensure the objectivity and adequacy of the results from different observers, several measures were taken. Observers underwent thorough training to understand observation protocols and minimize biases. Calibration exercises were performed to ensure that all observers interpreted and recorded data consistently. During these exercises, observers practiced by comparing their observations and resolving any differences. This process helped to standardize their approach before actual data collection. Additionally, the rubric was updated using frameworks from Ilma *et al*. [25], with student collaboration skills (C4) data scored between 1 and 4 if included in the rubric description.

2.5. Creating a scoring rubric

Inter-rater reliability is the degree to which various reviewers assign the same value to a specific variable. In this case, a rubric requirement. Inter-rater reliability was measured using a small number of raters who focused on assessing capstone experiences, communication, critical thinking, and the correlation coefficient. To design the rubric, Cohen's Kappa coefficient analysis was used as the formula to examine the dependability of the skill aspects. This analysis was critical in evaluating whether the expert evaluators agreed on the reliability of the rubric. Interpretation of Cohen's Kappa coefficient values are as: <0.00 signifies no agreement, 0.00-0.02 represents little to no agreement, 0.21-0.40 represents fairness, 0.41-0.60 represents moderateness, 0.61-0.80 represents substantial, and 0.81-1.00 shows nearly total agreement [26]. For this inquiry, two professional assessors were selected from the knowledge disciplines of children's education and educational measurement for children. The expert claimed that the experts have shown a high interrater reliability while using the rubric based on the Kappa value (κ=0.73).

Furthermore, to create a precise, complete, and user-friendly rubric, the criteria were altered based on the recommendations of professional assessor. The validity was considered when developing grading rubrics. To support the validity of an assessment tool, two types of evidence are frequently considered. Four expert assessors were recruited from two expertise fields: children's education and educational measuring for children. The content and construct validity were assessed, and it was determined that the expert assessors agreed that the rubric may be used because it can monitor the students' skills throughout the procedure.

2.6. Data analysis

Once more, in order to effectively explain the assessment, these rubrics are generated based on the needs of each test item. Four variables are derived from student scores: critical thinking, creativity, communication, and collaboration. Table 5 lists the criteria that were used to assess pupils' ability for 21st-century learning. This table employs a four-point criterion to enable a thorough assessment, offering greater precision, particularly in cases where distinctions between levels are subtle. This approach takes into account various factors, including learning conditions and student characteristics, as different groups may possess varying levels of prior knowledge [27]. The frameworks developed by Zulfaneti *et al*. [22] were used to modify these criteria. The test score was used to assess critical thinking, creativity, and communication skills, while the observation score was used to assess collaborative qualities. In this example, a test score is the outcome of a group's standardized or formal assessment, typically from a written exam. On the other hand, an observation score is based on an evaluator's direct observation of a group's performance, behavior, or skills, so it is impossible to have a score of 0. Evaluate students' organic chemistry ability by converting ratings to a scale. Additionally, Pearson's correlation coefficient was also used to determine the relationship between each indicator of 21st-century learning abilities (critical thinking, creativity, communication, and teamwork capabilities). Statistical tests were performed using IBM-SPSS version 26.

Table 5. Lists the student's criteria for critical thinking, creativity, communication, and collaboration skills

Observation score	Test score	Criteria
3.26-4.00	2.26-3.00	Very good
2.51-3.25	1.51-2.25	Good
1.76-2.50	0.76-1.50	Poor
1.00-1.75	0.0- 0.75	Very poor

3. RESULTS AND DISCUSSION

The study's conclusions focused on an examination of 21st-century learning abilities including creativity, critical thinking, and collaboration. These skills are detailed in Table 6. The study aims to understand the development and importance of these skills in today's education landscape.

Table 6. Evaluated 21st-century learning skills of students in organic chemistry

21st-century skills	Average	S.D.	Responses
Critical thinking			
Determine assumptions	1.53	0.52	Good
Formulate the main problem	1.93	0.70	Good
Discover information, ideas, and definitions to aid with problem-solving	1.53	0.64	Good
Evaluate the relevant arguments when solving problems	1.47	0.64	Poor
Total	1.62	0.31	Good
Creativity			
Product	1.53	0.52	Good
Content	2.07	0.80	Good
Connection	1.53	0.52	Good
Reflection	1.60	0.63	Good
Originality (Laboratory plan)	1.53	0.52	Good
Total	1.65	0.36	Good
Communication			
Purpose	1.93	0.80	Good
Content	1.67	0.82	Good
Organization (Writing survey)	1.60	0.63	Good
Organization (Laboratory plan)	1.53	0.52	Good
Total	1.68	0.33	Good
Collaboration			
Responsibility	2.53	0.52	Good
Respect one another	1.53	0.52	Very poor
Compromise	2.53	0.52	Good
Shared accountability	1.53	0.52	Very poor
Total	2.03	0.31	Poor

Based on the quantitative data, which details the student's performance in specific learning skills, it can be inferred that their overall performance is positive. The average scores for critical thinking, creativity, and communication skills from writing survey and collaboration skills from observation, all exceed 1.5, indicating proficiency in these areas. Moreover, the standard deviations (S.D.) accompanying each score suggest relatively low variability, underscoring the consistency of performance across these skills. For instance, the total average scores for critical thinking, creativity, communication, and collaboration skills were 1.62 (S.D.=0.31), 1.65 (S.D.=0.36), 1.68 (S.D.=0.33), and 2.03 (S.D.=0.31), respectively. These findings collectively support the conclusion that students demonstrate commendable proficiency in the specified 21st-century learning skills within the context of organic chemistry. Priyatni and Martutik [28] found that students' abilities in critical thinking, creativity, innovation, communication, and teamwork improved in the study of chemical equilibrium. Research by Suyanta [15] emphasized that understanding chemistry as part of overall education helps students develop these 21st-century skills, enhancing their global competitiveness.

The positive survey results suggest that the current teaching methods are effective, but they also highlight areas for improvement. Potential changes in teaching chemistry could include using detailed group data to tailor instruction, addressing specific weaknesses and building on strengths, integrating real-world applications to make lessons more engaging, and developing new assessment tools that better track the development of 21st-century skills [15]. By analyzing these results, the school can make informed decisions to enhance its chemistry program and better prepare students for future challenges. Despite the good overall survey results, teamwork was found to be lacking, and these findings are specific to the given school. Collecting data per group provides detailed insights into how different student groups perform and what they need, making the results more useful. This approach helps identify specific strengths and weaknesses within each group, allowing for targeted improvements in teaching strategies. Group-level data can reveal patterns and trends that broader analyses might miss, ensuring the educational program is better tailored to improve learning outcomes for all students [16]. Including representative examples in the study can illustrate the practical application of the rubrics and show how they contribute to a detailed assessment of student skills. This makes the evaluation process more transparent and relatable, providing a richer understanding of how students' performances are assessed and how the educational program can be tailored to support their development.

Additionally, the researchers hope to investigate the relationships among the 21st-century learning competencies, as indicated in Table 7. A statistical study of the correlation coefficient (r) was carried out to evaluate and ascertain the relationship between each talent. This investigation sheds light on potential connections between these abilities.

Table 7. The correlation coefficients (r) for every 21st-century learning skill

21st-century educational abilities	Critical thinking	Creativity	Communication	Collaboration
Critical thinking	1			
Creativity	0.58*	1		
Communication	0.60*	0.66**	1	
Collaboration	0.69**	0.69**	0.54*	1

*The correlation is significant at the 0.05 level
** The correlation is significant at the 0.01 level

Furthermore, a calculation was made to determine the correlation between every score on the 21st-century learning skill disposition. The coefficient of determination is the square of correlation, which can be positive or negative and range from 0.00 to 1.00 [29]. The results show that the different values of each skill have strong, positive connections with one another. It has been repeatedly demonstrated that critical thinking and creative skills are associated. The links between creativity, communication, and cooperation skills were discovered. Additionally, connections between cooperation and communication skills were discovered.

According to the results presented in Table 7, there are significant positive correlations among 21st-century learning skills, particularly between critical thinking and creativity ($r=0.58$, $p<0.05$), communication ($r=0.60$, $p<0.05$), and collaboration ($r=0.69$, $p<0.01$). This suggests that improvements in critical thinking are moderately associated with better creativity, communication, and collaboration skills. Ülger [30] also found a positive link between creative and critical thinking skills. Creativity and communication have a moderate positive correlation ($r=0.66$, $p<0.01$), with Wang [31] noting that practicing creativity and critical thinking, especially through reading and writing, enhances creativity. Research by Mareque and Prada [32] emphasized that opportunities to develop communication skills are crucial for unlocking students' creative potential.

Additionally, collaboration is moderately correlated with creativity ($r=0.69$, $p<0.01$); Sawyer [33] noted that groups generate more innovative solutions than individuals, and Almajed *et al*. [34] observed that diverse groups improve learning outcomes. There is a moderate positive association between collaboration and communication skills ($r=0.54$, $p<0.05$). Zakiah *et al*. [35] found that as students' collaboration skills improve, their communication abilities also increase. Additionally, Fianti *et al*. [36] discovered a strong correlation between students' abilities to collaborate and communicate. As students become better at collaborating, their communication skills also improve. Erickson [37] suggested that exploratory learning enhances cooperation skills, improves attitudes toward teamwork, and boosts confidence in presenting. Overall, it underscores the interrelatedness of these essential 21st-century skills, highlighting how improvements in one area tend to be associated with enhancements in others. The significant correlations, particularly those at the 0.01 level, emphasize the strength of these relationships.

4. CONCLUSION

The 4Cs model of 21st-century learning skills was implemented by organizing students into small groups of 5–6, based on their academic backgrounds, particularly previous chemistry coursework. The results showed that students exhibited strong critical thinking, creativity, and communication skills in organic chemistry, but their collaboration skills were lacking. Critical thinking involved analyzing complex reactions, understanding properties, and evaluating data. Creativity was demonstrated through proposing novel synthesis routes and designing experiments. Communication was crucial for presenting data and explaining concepts, while collaboration was fostered through group work on lab experiments and projects. In the next stage, each skill was explored to encourage conceptual change based on the constructivist correlation between each indicator and 21st-century learning skills. The findings revealed a moderate positive association between each skill, indicating that critical thinking, creativity, communication, and collaboration are interconnected. Enhancing one skill often leads to improvements in others, highlighting the importance of a holistic approach to developing 21st-century educational abilities. Researchers discovered that students had low collaboration proficiency, possibly due to a lack of experience working in teams or insufficient social skills. To improve both teaching and learning, we aim to create a more interactive and cooperative learning environment.

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