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The Effect of Citizen Science Project Learning Model on Students' Critical and Creative Thinking Skills

Adnan[1], Sitti Saenab[2], Rahmatullah[3], Rifka Almunawarah[1], Sahla Sahira[1]*

[1]Department of Biology Education, Makassar State University, Makassar, Indonesia,
e-mail: adnan@unm.ac.id; rifkaalmunawarah1@gmail.com; sahlasahira02@gmail.com
[2]Department of Science Education, Makassar State University, Makassar, Indonesia, e-mail: sitti.saenab@unm.ac.id
[3]Department of Economic Education, Makassar State University, Makassar, Indonesia, e-mail: rahmatullah@unm.ac.id

Abstract: Critical and creative thinking skills are essential in 21st-century education, but conventional learning approaches are still less effective in developing these skills. This study aims to analyze the influence of the Citizen Science Project learning model on the critical and creative thinking skills of high school students in Indonesia. The research method used experiments with post-test control groups, involving 70 students divided into experimental and control groups (35 students each). Instruments in the form of essay questions were used to measure students' critical and creative thinking skills, while data were analyzed using quantitative descriptive analysis and inferential statistics using the MANOVA test. The results showed that the Citizen Science Project model significantly improved students' critical and creative thinking skills compared to conventional learning ($p < 0.05$). This improvement demonstrates the effectiveness of the model in facilitating high-level thinking skills. These findings indicate that the Citizen Science Project can be an innovative strategy in learning to improve 21st-century skills. Therefore, this model is recommended to be applied in Education.

Keywords: *citizen science project, critical thinking skills, creative thinking skills, student.*

Introduction

The quality of education in Indonesia still faces significant challenges at the international level. Based on the UNESCO report, Indonesia ranks 64th out of 120 countries in terms of quality of education. In addition, the education development index 2015 shows that Indonesia ranks 57th out of 115 countries. The latest data from the Programme for International Student Assessment (PISA) in 2022 reveals that the quality of education in Indonesia is still relatively low, ranking 68th out of 81 countries. These findings reflect the low ability of students to think critically, think creatively, interpret information, and solve problems in various aspects of life. This low ranking also indicates a decline in academic achievement globally (learning loss), which requires serious attention from various parties.

One of the main causes of the low quality of education in Indonesia is the dominance of a learning system that is still teacher-centered, memorization-oriented, and evaluation that emphasizes low-level cognitive aspects. This is in contrast to countries such as Finland, Singapore, and Japan that have adopted inquiry-based, project-based, and collaborative learning approaches. The education system in Indonesia still faces challenges in developing learning strategies that are oriented towards strengthening higher-order thinking skills (HOTS).

The development of HOTS-oriented learning is one of the programs developed by the Ministry of Education as an effort to improve the quality of learning and the quality of graduates (Adnan et al., 2014; Maryani et al., 2021). In addition, the HOTS capability is also applied to catch up with Indonesia's ranking in PISA and Trends in International Mathematics and Science Study (TIMSS) compared to other countries (Rindermann and Baumeister, 2015; Adnan and Bahri, 2018). Countries that excel in implementing HOTS

*Corresponding author: adnan@unm.ac.id

learning have strategic approaches to overcoming education problems. For example, Finland relies on personalized learning and a flexible curriculum by giving teachers broad autonomy; Singapore emphasizes a competency-based curriculum focusing on problem-solving and logical reasoning; and Japan strengthens a collaborative and reflective learning culture through lesson studies and classroom discussions. These approaches have proven to be effective in improving students' quality of education and higher thinking skills.

HOTS abilities are closely related to critical and creative thinking competencies that are key needs in 21st-century learning (Eskiyurt and Özkan, 2024; Hews et al., 2023; Ghanizadeh et al., 2024; Hikamah et al., 2021). Critical thinking skills can be trained through systematic and specific analysis and identification of problems, as well as designing strategies as solutions to problems faced in the surrounding environment (Almunawarah et al., 2023; Fabian et al., 2024; Mahanal et al., 2019). Meanwhile, creative thinking skills can be developed through efforts to find innovative solutions, analyze problems from various perspectives, and generate unique ideas (out of the box) that are integral parts of advanced thinking skills (Rohman et al., 2024; Adnan et al., 2021; Nurjanah et al., 2024; Juniati and Budayasa, 2024).

The main problem faced by education in Indonesia is students' low critical and creative thinking skills. This lack of high-level thinking skills suggests that many students still have difficulty analyzing information, solving complex problems, and coming up with innovative ideas. Traditional learning systems that focus on memorization and passive mastery of material are factors that slow down the development of students' thinking skills (Bremner et al., 2023; Woods and Copur-Gencturk, 2024). This condition is a challenge for educators in providing learning by the demands of the 21st century. One approach that has the potential to be an effective solution is the Citizen Science Project (CSP) learning model.

Theoretically, CSP is rooted in constructivist (Vygotsky, 1978) and experiential learning (Kolb, 1984) approaches that emphasize that knowledge is built through direct experience, social interaction, and reflection. In CSP, students are actively involved in real scientific processes such as data collection, field observation, and results analysis. These activities encourage the development of high-level thinking skills such as analysis, evaluation, critical thinking, and creation (Bloom's Revised Taxonomy). A number of studies also support the effectiveness of CSP in increasing HOTS. Bonney et al. (2009) show that participation in citizen science projects can improve scientific literacy and critical thinking skills. Ballard et al. (2017) and Stein et al. (2023) found that involvement in CSP helps students develop analytical and evidence-based problem-solving skills. Zoellick et al. (2012), Sanabria et al. (2022), Gray et al. (2012), and Edson et al. (2024) affirm that CSP facilitates reflective and systemic thinking because students are directly involved in real issues. In addition, Mitchell et al. (2017) and Jadallah and Wise (2023) also show that CSP supports scientific inquiry, data analysis, and argumentation skills. Thus, in theory and practice, CSP has proven to be effective in developing HOTS through authentic, contextual, and socially meaningful learning.

When compared to other learning models, CSP has its own uniqueness. Problem-based Based Learning (PBL) focuses on solving hypothetical problems in the classroom, and inquiry-based Based Learning (IBL) emphasizes the process of scientific inquiry, while CSP combines both approaches in a real-world context. Similarly, compared to Project Based Learning (PJBL), which focuses on the design and implementation of projects by students, CSP has additional depth in involvement in authentic scientific processes and real contributions to producing knowledge or solutions used by scientific communities or institutions. If PJBL student projects tend to be simulative or internal in the school environment, then in CSP, the students' work results are real, documented, and can be used by the public or stakeholders. Therefore, CSP is relevant in strengthening HOTS and plays a strategic role in shaping students' civic awareness and social responsibility. Integrating scientific learning, social engagement, and tangible contributions makes CSP a transformative learning model in the 21st-century education era.

Although previous research has shown that CSP is able to improve scientific literacy and critical thinking skills, most of the studies still focus on overseas contexts, especially in countries with well-established education systems. In addition, most of the research emphasizes the participatory aspects and general impacts on science literacy but has not specifically examined how CSP contributes to the measurable development of HOTS in formal education, particularly in Indonesia. These limitations create a gap in understanding the effectiveness of CSP as an innovative learning strategy in the local environment that is still dominated by memorization approaches and teacher-centered learning. Therefore, this study aims to fill this gap by empirically examining the influence of the implementation of CSP on the development of student HOTS in Indonesia and adapting it to the characteristics of the national curriculum and the dynamics of learning in the classroom.

The Citizen Science Project learning model consists of seven stages: project problem orientation, project planning, timeline creation, project implementation, project monitoring, project assessment, and project evaluation. These stages were developed by adapting project-based learning models but have important differences. In CSP, there is community involvement in data collection, expert involvement in the mentoring process, and integration of web-based learning technology equipped with learning resources and practical guidance for project implementation. Through these stages, researchers will observe their impact on improving students' critical and creative thinking skills. The results of this research are expected to be a foundation for policy makers, educators, and other stakeholders in designing more effective learning strategies to improve the quality of education in Indonesia.

Materials and Methods

Population and Sample

The population in this study is all students of class X of SMAN 9 Makassar for the 2024/2025 school year. The research sample consisted of two classes that were selected using the intact group sampling technique, which is the selection of groups that have formed naturally without changes in composition. The sample totaled 70 students, with details of 35 students as the experimental group and 35 students as the control group.

Both classes have similar initial characteristics based on the previous semester's report card scores and come from relatively homogeneous socioeconomic backgrounds. There was no pre-test because this study used a post-test only control group design, but the class selection considered the equivalence of the initial academic level to minimize bias.

Research Design and Procedure

This study uses a post-test-only control group design. The experimental group was given the Citizen Science Project (CSP) learning model, while the control group used the Student Team Achievement Division (STAD) model.

The implementation of the intervention lasted for three months, with 12 meetings in each class for two hours of lessons (2 × 45 minutes) per meeting. In the experimental class, the CSP model is implemented through seven main stages: (1) Project problem orientation, students recognize environmental problems around, especially those related to biodiversity. (2) Creation of a project plan, collaborating with group members to formulate project objectives and methods. (3) making a timeline, adjusting the activity schedule to suit the time and existing resource limitations. (4) Project implementation is done through field observation, recording, and visual documentation. Students analyze the data obtained, draw conclusions, and discuss collaboratively. (5) Monitor the project, report progress and obstacles faced, discuss in groups to find solutions, and reflect on the process that has been passed. (6) Project assessment, presenting project results. (7) evaluate the project, write personal and group reflections on the project experience, discuss the learnings gained, and provide project input for future improvement

The researcher served directly as the teacher in both classes: the experimental class, which implemented the Citizen Science Project (CSP) model, and the control class, which used the Student Teams Achievement Division (STAD) model. This ensured consistent and procedural implementation of both learning models as designed.

Research Instruments

The instruments used to measure students' critical thinking abilities are essay tests that refer to the FRISCO model developed by Ennis et al. (2005), Ennis and Millman (2008), and Ennis (2011), with indicators of focus, reason, conclusion, situation, clarity, and review. Meanwhile, creative thinking ability was measured using an essay test based on indicators developed by Guilford (1950, 1967, 1968), with indicators of fluency, flexibility, originality, and detail.

All questions are adjusted to the context of biology learning, especially the biodiversity material. The instrument has gone through an expert validation process using Aiken's V, with an average V value of ≥ 0.87, indicating high content validity. The reliability of the instrument was tested using Cronbach's Alpha, with $\alpha = 0.81$ for the critical thinking test and $\alpha = 0.85$ for the creative thinking test, indicating high reliability.

Data Analysis

The data from the post-test results was analyzed through several stages. First, prerequisite tests are carried out as normality and homogeneity tests to ensure the data meets inferential statistical assumptions. Furthermore, to test the research hypothesis, an analysis was carried out using Multivariate Analysis of Variance (MANOVA) by looking at the values of Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. The Pillai's Trace value is a positive value with an increased value statistic indicating an effect that contributes more to the model, and Wilks' Lambda is a positive statistical value that ranges from 0 to 1, with a smaller value indicating a more contributing effect to the model. Hotelling's Trace with an increased positive value shows a more contribution effect to the model, and Roy's Largest Root gives the same value as Hotelling's Trace; there is a strong correlation between dependent variables (Sarwono, 2017). In addition to MANOVA, an independent sample t-test was also carried out to compare the average scores between the experimental and control groups. Hypothesis testing was carried out using SPSS 24 software for Windows, with the basis for decision-making that if the significance value (2-tailed) < 0.05, then H0 is rejected and H1 is accepted, which means that there is a significant difference between the experimental group and the control group in improving critical and creative thinking skills, and if the significance value (2-tailed) > 0.05, then H0 is accepted and H1 is rejected. which means there is no significant difference between the two groups (Herzog et al., 2019). With this method, the study aims to prove that the Citizen Science Project learning model has a more significant influence than the STAD model in improving high school students' critical and creative thinking skills.

Results

Critical and Creative

Based on Table 1, it can be observed that the average value of the critical thinking and creative ability class of the experimental class was higher than that of the control class. The average critical thinking ability of the experimental class was 69.89, while the control class was 56.86. Therefore, the difference between the two is 13.03. The average creative thinking ability of the experimental class was 70.80, while the control class was 54.00, so the difference between the two was 16.8. The highest score of critical thinking in the experimental class was 98.00, and the highest score of creative thinking was 91.00, while in the control class, the highest score of critical thinking was 78.00, and the highest score of creative thinking was 72.00. Furthermore, for the standard deviation of the experimental class, 12.98 is critical thinking, and 10.38 is creative thinking. The standard deviation of the control class was 11.19 for critical thinking and 8.39 for creative thinking.

Table 1. *Critical and creative descriptive statistics of students in experimental and control classes*

No.	Statistics	Critical Thinking		Creative Thinking	
		Experiment Class	Control Class	Experiment Class	Control Class
1	Sample Quantity	35	35	35	35
2	Average	69.89	56.86	70.80	54.00
3	Highest Score	98.00	78.00	91.00	72.00
4	Lowest Score	48.00	40.00	44.00	41.00
5	Standard deviation	12.98	11.19	10.38	8.39

This quite striking difference in average scores shows statistical significance and has practical implications in the context of learning. According to Cohen (1988), a difference of more than 0.8 standard deviations can be categorized as a significant effect in education. With a score difference of more than 13 points (for critical thinking) and 16 points (for creative thinking), these results show that the use of the Citizen Science Project (CSP) learning model provides a significant and substantial improvement in students' cognitive achievement.

The value of critical and creative thinking skills is then grouped by category based on the students' post-test results. Table 2 shows the frequency distribution and percentage of critical and creative thinking skills in both the control class and the experimental class.

Table 2. *Distribution of frequency and percentage of students' critical and creative thinking skills in the classroom Experimental and controls*

No.	Category	Critical Thinking				Creative Thinking			
		Experiment Class		Control Class		Experiment Class		Control Class	
		F	%	F	%	F	%	F	%
1	Very High 81 ≤ x ≤ 100	9	25.71	0	0	7	20.00	0	0
2	Good 61 ≤ X < 80	17	48.57	11	31.43	22	62.86	9	25.71
3	Simply 41 ≤ X < 60	9	25.71	23	65.71	6	17.14	26	74.29
4	Less 21 ≤ X < 40	0	0	1	2.86	0	0	0	0
5	Very low X < 20	0	0	0	0	0	0	0	0

The results of critical and creative thinking skills obtained by students in Table 2 interpret that the critical thinking skills in the experimental class were 9 (25.71%) students who obtained very high results, there were 17 (48.57%) classified as good, and there were 9 (25.71%) classified as adequate. Meanwhile, 11 (31.43%) were classified as good, 23 (65.71%) were classified as adequate, and 1 (2.86%) was classified as lacking. The interpretation of creative thinking skills in the experimental class was 7 (20.00%) classified as very high, there were 22 (62.86%) classified as good, and there were 6 (17.14%) classified as sufficient. While 9 (62.86%) of the control class were classified as good and 26 (74.29%) were classified as adequate, From the data, it can be seen that students in the experimental class tend to have a higher distribution in the "Very High" and "Good" categories than the control class. This reflects that the Citizen Science Project's learning model is more successful in improving students' high-level thinking skills.

Normality Test

Based on the Kolmogorov-Smirnov normality test results in Table 3, the significance value (Sig.) is greater than 0.05, meaning the data is usually distributed. In addition, the homogeneity test was carried out using the Levene test and the Kovarian Box matrix equivalence test. The results of the Levene test showed that the Sig. value for critical thinking skills was 0.351 and for creative thinking skills was 0.312, both of which were greater than 0.05, so the data were declared homogeneous. The use of the Box covariance matrix equivalence test yielded a Sig. value of 0.263 also showed that the data were homogeneous

Table 3. *Normality Results*

	Learning Model	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig. > 0.05
Critical Thinking	Model Citizen Science Project	.096	35	.200
	STAD model	.145	35	.060
Creative Thinking	Model Citizen Science Project	.074	35	.200
	STAD model	.134	35	.113

Hypothesis Test

The prerequisite test for the MANOVA analysis has been completed, so the results of the MANOVA test can be used for hypothesis testing. Based on the results of Table 4, it shows four significance tests for each of the model's effects of the Pillar Trace value of 0.453, which means that it has a more contribution effect on the model, Wilks' Lambda value of 0.547, which gives a more contribution effect to the Hotelling's Trace value model of 0.830 equal to the value of Roy's Largest Root which means that there is a strong correlation between the dependent variables and for the F coefficient is 27.792 with a Sig. 0.00, and the Partial Eta Squared is 0.453, which shows that the treatment explains 45.3% of the variance in students' critical and creative thinking abilities. This shows a difference in the ability to think critically and creatively between students who are taught with the Citizen Science Project and STAD learning models.

Table 4. *MANOVA test analysis results*

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.981	1691.644	2.000	67.000	.000	.981
	Wilks' Lambda	.019	1691.644	2.000	67.000	.000	.981
	Hotelling's Trace	50.497	1691.644	2.000	67.000	.000	.981
	Roy's Largest Root	50.497	1691.644	2.000	67.000	.000	.981
Treatment	Pillai's Trace	.453	27.792	2.000	67.000	.000	.453
	Wilks' Lambda	.547	27.792	2.000	67.000	.000	.453
	Hotelling's Trace	.830	27.792	2.000	67.000	.000	.453
	Roy's Largest Root	.830	27.792	2.000	67.000	.000	.453

Based on the findings of the analysis in Table 5. The results of the ability to think critically and creatively have a partially significant impact. The results of the Tests of Between-Subject Effects study showed in detail that the value of F was 20.184 with a Sig. of 0.00, which was less than 0.05. This shows that the learning model given influences critical thinking skills. In addition, an F value of 55.336 with a Sig. of 0.00, less than 0.05, and Partial Eta Squared of 0.229 (22.9%) and creative thinking of 0.449 (44.9%). Thus, it was revealed by the analysis of Tests of Between-Subject Effects that the learning model provided influenced the ability to think creatively. The influence of the CSP model on creative thinking skills is more significant than on critical thinking skills. This is most likely related to the natural characteristics of the Citizen Science Project, which is 1. to encourage open exploration and diverse problem-solving approaches, 2. Involve students in real projects that do not have one definitive answer, 3. provides ample space for students to innovate and express ideas in an original way.

The nature of community-based scientific projects that demand creativity and originality in developing solutions allows students to show divergent thinking, i.e., the ability to think creatively in various directions. In contrast, more structured critical thinking is still improving, but not as high as creative thinking skills because it may require additional instructional reinforcement

Table 5. *Results of test analysis of between-subjects effects*

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Berpikir_kritis	2970.514a	1	2970.514	20.184	.000	.229
	Berpikir_kreatif	4939.200b	1	4939.200	55.336	.000	.449
Intercept	Berpikir_kritis	281115.657	1	281115.657	1910.091	.000	.966
	Berpikir_kreatif	272563.200	1	272563.200	3053.628	.000	.978
Treatment	Berpikir_kritis	2970.514	1	2970.514	20.184	.000	.229
	Berpikir_kreatif	4939.200	1	4939.200	55.336	.000	.449
Error	Berpikir_kritis	10007.829	68	147.174			
	Berpikir_kreatif	6069.600	68	89.259			
Total	Berpikir_kritis	294094.000	70				
	Berpikir_kreatif	283572.000	70				
Corrected Total	Berpikir_kritis	12978.343	69				
	Berpikir_kreatif	11008.800	69				

The analysis results in Table 6 show that the CSP model significantly increases critical thinking scores by 13,029 points and creative thinking by 16,800 points (Sig. = 0.000). This difference is not only statistically significant but also practical in the context of education, as an increase above 10 points on a scale of 100 can have a tangible impact on students' achievement and high-level thinking readiness. Overall, these results confirm that using the Citizen Science Project learning model is significantly more effective in improving creative thinking skills while still making a meaningful contribution to improving students' critical thinking skills.

Tablel 6. *Parameter estimates*

Dependent Variable	Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
						Lower Bound	Upper Bound	
Berpikir Kritis	Intercept	56.857	2.051	27.727	.000	52.765	60.949	.919
	CSP	13.029	2.900	4.493	.000	7.242	18.815	.229
	STAD	0[a]	.	.	.	.	.	.
Berpikir Kreatif	Intercept	54.000	1.597	33.814	.000	50.813	57.187	.944
	CSP	16.800	2.258	7.439	.000	12.293	21.307	.449
	STAD	0[a]	.	.	.	.	.	.

Discussions

The study results show that the Citizen Science Project (CSP) model can improve students' critical and creative thinking skills. Students involved in this project are more active in collecting data, analyzing information, and solving problems. This is in line with Adnan et al. (2024), Adnan et al. (2025) who stated that CSP divides the learning process into seven main steps: (1) project problem orientation, (2) project plan creation, (3) timeline creation, (4) project implementation, (5) project monitoring, (6) project assessment, and (7) project evaluation. Following these steps makes the learning environment more engaging, and students are more motivated to solve problems. They learn theory and apply fundamental skills that will be useful in the future, improving their critical and creative thinking abilities.

Critical thinking skills are the primary foundation that supports the development of high-level thinking skills, which include analytical and evaluation skills (Gavronskaya et al., 2022; Malik and Ubaidillah, 2020; Molokhina et al., 2021). These results are reflected in the CSP syntax, particularly at the stage of problem orientation, project planning, and timeline development. Learning strategies such as problem-based and project-based learning are effective in developing students' critical thinking (Sahira et al., 2023; Na et al., 2022; Sahira, 2023). This strategy encourages students to become critical thinkers (Eskiyurt and Özkan, 2024; Ma, 2023), which is seen as students drawing up project plans based on real problems. Students are given the role of researching, evaluating, and processing information from various sources to activate critical thinking skills (Angelelli et al., 2023; Jiang, 2022; Belousova, 2020). The syntax of project implementation, project monitoring, project assessment, and evaluation in CSP reflects these activities in real terms. Therefore, CSP is relevant and appropriately used to improve students' critical thinking skills because it makes critical thinking skills the core of the overall project process.

Creative thinking skills involve the merging of divergent and logical thinking. Divergent thinking is used to explore various ideas and solutions, while logical thinking is needed to evaluate and develop such solutions concretely (Lee et al., 2020; Ristic et al., 2023; Akhmetsapa et al., 2024; Waskito et al., 2024). This can be seen in the CSP syntax, especially at problem orientation, project planning, timeline creation, and project implementation. Students are encouraged to generate original ideas, formulate creative questions, and develop innovative solutions (Yildiz and Guler, 2021; Hews et al., 2023; Zdanevych et al., 2020). During project monitoring, assessment, and evaluation, students are trained to refine their solutions, reinforce originality, and creatively evaluate results. CSP facilitates exploration, innovation, and adaptation in the face of challenges, making it an effective model for developing creative thinking skills.

Table 1 shows that CSP significantly impacts critical and creative thinking skills more than the STAD learning model. This is due to the active and contextual learning approach that CSP offers. Each stage in the CSP syntax systematically encourages the development of students' thinking skills, from problem orientation that builds connections to real issues to in-depth project reflection. Table 2 corroborates these findings by showing that most students in the experimental class were in the good and excellent categories, which is inversely proportional to the distribution in the control class. This suggests that statistically significant differences in scores also reflect a practically meaningful effect in the context of learning. For example, the average critical thinking score of the experimental group was 69.89 compared to 56.86 in the control group, indicating that CSP was not only statistically superior but also had a real impact in encouraging the improvement of the quality of students' thinking in the classroom.

Nonetheless, it is necessary to explain further how the CSP mechanism is specifically superior to STAD. STADs rely more on cooperative learning in fixed groups and merit-based task sharing, while CSPs provide greater exploratory freedom and genuine engagement with communities and authentic issues. The involvement of experts and digital platforms adds value to CSPs, which is not found in the STAD approach. However, the effectiveness of CSP can also be influenced by several external factors, such as teacher support, student motivation, and the availability of digital resources. Therefore, CSP's advantage in improving HOTS comes from the model itself and its supporting ecosystem.

The MANOVA analysis and the Test of Between-Subjects Effects test showed that CSP significantly influenced both thinking skills. However, the Partial Eta Squared value for creative thinking (0.449) is higher than critical thinking (0.229), which means that CSP has a more significant influence on the creative aspect. This can be explained through the characteristics of CSP, which are based on exploration, idea submission, open collaboration, and interaction with real contexts that further challenge students' creativity. A flexible approach to problem-solving and community involvement in projects enriches students' perspectives, encouraging them to develop new and original solutions.

Integrating CSP with digital technology through the website platform also strengthens its effectiveness. Students can upload data, discuss with experts and the community, and access online learning resources. This supports a collaborative, open, and continuous learning process. The website also allows the community to be actively involved, enriching the student learning experience and encouraging the creation of a participatory learning ecosystem.

However, the implementation of CSP also has its challenges. This model is optimal for students with good independent learning and collaboration skills. Students who are still familiar with passive learning or have limitations in managing projects may have difficulty following the CSP syntax. In addition, the success of the implementation is highly dependent on the competence of teachers as active facilitators, as well as the readiness of the technological infrastructure. Technical obstacles such as limited devices, uneven internet access, and limited time in the curriculum are obstacles in themselves. Resistance from teachers and students can also arise if they are not familiar with the project-based approach and community involvement.

In addition, there are still limitations in the literature that reviews the failure or ineffectiveness of CSP. Previous studies have tended to emphasize the success of CSP, while studies showing that CSP does not have a significant impact on Higher Order Thinking Skills (HOTS) are still very limited. Therefore, the findings in this study can be an important contribution to strengthening the empirical evidence regarding the effectiveness of CSP. However, it takes follow-up studies with different contexts, populations, and subject areas to test the consistency of these findings.

The practical implications of this study are important to elaborate further. If CSP proves effective, teachers can integrate this model into the curriculum through subjects such as science, social studies, or Language, as long as the learning topic contains elements of real problems that can be researched and solved collaboratively. This model can also be adapted to cross-subject learning through thematic projects. For schools with large student numbers, CSP can be implemented as small group work to be more effective. Teacher training, time flexibility, and technological support are the keys to its successful implementation. Thus, CSP can be an adaptive, collaborative, and contextual learning approach in developing students' HOTS at various levels and conditions of educational units.

Conclusions

The Citizen Science Project (CSP) model has proven effective in improving students' critical and creative thinking skills. The analysis results show that CSP's influence is more substantial on creative thinking skills, which can be seen from the higher Partial Eta Squared value compared to the critical thinking aspect. CSP's syntax emphasizing exploration, collaboration, and real-world problem-solving provides space for students to actively engage in meaningful learning processes. This model can be applied flexibly across a range of subjects, not limited to science and STEM, as long as the learning topic is relevant to the authentic issue for which the project can be used. Teachers play an important role as facilitators, and technology support is the main factor in implementing CSP in the classroom.

For wider implementation, education policies that support the integration of CSP in the curriculum are needed, including teacher training, flexible time allocation, and adequate digital infrastructure. Further research is recommended to examine the long-term impact of CSP implementation and explore other variables such as gender differences, student learning styles, or school characteristics. Thus, the effectiveness of CSP can be tested in various contexts and produce learning models that are more inclusive and adaptive to the needs of learners in the 21st-century learning era.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualisation: Adnan, Sitti Saenab, and Rahmatullah; Data curation: Adnan, Rifka Almunawarah, and Sahla Sahira; Formal analysis: Adnan, Rahmatullah, and Rifka Almunawarah; Funding acquisition: Adnan; Investigation: Adnan, Sitti Saenab, Rahmatullah, Rifka Almunawarah, and Sahla Sahira; Methodology: Adnan, Sitti Saenab, and Rifka Almunawarah; Project administration: Adnan; Resources: Adnan and Sitti Saenab; Software: Adnan; Supervision: Adnan; Validation: Adnan and Rahmatullah; Visualization: Adnan and Rifka Almunawarah; Writing – original draft: Adnan and Sitti Saenab; Writing – review and editing: Adnan, Rahmatullah, Sitti Saenab, and Rifka Almunawarah. All authors have read and approved the final version of the manuscript for submission.

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