# The Effectiveness of a Deep Learning Oriented Citizen Science Project Learning Model in Improving Students' Science and Digital Literacy

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**Abstract**
Low levels of science and digital literacy among students pose a challenge in 21st-century education. This study aims to analyze the effectiveness of the Deep Learning-oriented Citizen Science Project (CSP) learning model in improving students' science and digital literacy. The study employed a quasi-experimental method using a non-equivalent control group pretest-posttest design. The sample consisted of 134 11th-grade students from a public high school, divided into three experimental classes and one control class. Research instruments included a science literacy test and a digital literacy questionnaire. Data analysis was conducted using ANCOVA and Tukey's HSD post-hoc test. The results showed that the Deep Learning-oriented CSP learning model had a significant effect on improving students' science literacy ($F = 157.422$; $p < 0.001$; $\eta p^2 = 0.785$) and digital literacy ($F = 492.705$; $p < 0.001$; $\eta p^2 = 0.920$). The results of the study indicate that the Deep Learning-oriented CSP learning model has a significant effect on improving students' science literacy and digital literacy, with a significance level of $p < 0.05$. Students in the experimental class demonstrated higher abilities than those in the control class in understanding scientific phenomena, solving problems, and utilizing digital technology in learning. Authentic science-based project-based learning, collaboration, and the use of digital platforms foster meaningful and contextual learning. Thus, the Deep Learning-oriented CSP model is effective in supporting the development of students' 21st-century competencies, such as science literacy and digital literacy.

## 1. Introduction

Twenty first century education demands a generation that not only excels in scientific knowledge but is also adaptable to advancements in digital technology. The integration of science and technology is a key factor in shaping students capable of addressing global challenges through the development of critical, creative, and collaborative thinking skills, as well as evidence-based decision-making (Markwick & Reiss, 2025; Aldi et al., 2025). In line with this, national education policy emphasizes the importance of science and digital literacy in the Merdeka Curriculum, as outlined in Ministry of Education, Culture, Research, and Technology Regulation No. 12 of 2024, which emphasizes project-based learning and STEM integration to promote meaningful, contextual learning focused on character development (Sudarmin et al., 2023; Supiyono, 2025). International studies reveal low levels of science literacy among Indonesian students. PISA and TIMSS reports indicate that Indonesia remains below the OECD average and ranks outside the top 70 globally (Ramli et al., 2022). Research by Kadir et al., (2025) reports an average science literacy score of only 39.7%, while Adnan et al. (2021) found that only 17% of students understand the scientific method. This situation illustrates that understanding scientific concepts, critical thinking skills, and the ability to make decisions based on data and facts remain challenges in science education (Sutiani et al., 2021).

In addition to science literacy, digital literacy also poses a major challenge. The National Digital Literacy Roadmap indicates that Indonesia still ranks low on the Information and Communication Technology (ICT) Development Index, at 114th place in 2016 and 111th in 2017 (Andika et al., 2025). Although the 2024 Indonesian Digital Society Index score indicates that basic technological proficiency is already quite good (Wahjusaputri & Nastiti, 2022; Nyoman et al., 2024). However, its utilization has not been optimal for productive activities by teachers and students in creating interactive, technology-based collaborative learning (Midtlund et al., 2021). This is reflected in the tendency for the use of digital devices in schools to still focus heavily on entertainment and challenges such as technology dependency, resulting in their underutilization in learning (Khahro & Javed, 2022; Kamilova et al., 2023; Helal & Helal, 2025). This aligns with the findings Ana et al., (2025) which confirm that blended learning models can improve digital literacy when devices and online platforms are used in a structured manner to support the learning process.


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These low levels of science and digital literacy call for a learning model capable of integrating authentic scientific experiences, real-world problem-solving, and the use of digital technology. One model that aligns with these characteristics is the Citizen Science Project (CSP), which evolved from the citizen science movement that has involved the public in scientific research since the 1990s (Phillips et al., 2018; Roche et al., 2020). CSP involves students in data collection, analysis, and collaboration with experts (Adnan et al., 2025)Adnan et al., 2024; Adnan et al., 2025; Aristeidou & Herodotou, 2020) as well as the interpretation of scientific phenomena relevant to daily life and crucial for the development of soft skills in the modern era (Adnan et al., 2024; Adnan et al., 2024; McKenney et al., 2024; Zhang et al., 2023). CSP utilizes digital technology for data uploading, analysis, and integration using platforms such as Zooniverse, nQuire, EU-Citizen, Budburst, and CSS (Philips et al., 2018; Baudry et al., 2022). CSP models have proven effective in enhancing 4C skills. Previous research findings indicate that CSP can improve creative thinking skills by 44.9% and critical thinking skills by 22.9% (Adnan et al., 2025).

The strength of the CSP learning model in fostering meaningful learning demonstrates its alignment with the Deep Learning approach currently gaining traction in Indonesia, as outlined in Ministry of Education and Culture Regulation No. 13 of 2025, which establishes the Deep Learning approach as the foundation of the national curriculum through three principles: mindful, meaningful, and joyful. The DL approach is viewed as capable of facilitating knowledge transformation (Jin et al., 2025), while reinforcing Piaget's constructivist principles that emphasize the importance of direct experience, active interaction, and cognitive adaptation (Maurya & Khan, 2021; Zhang, 2020). Both CSP and Deep Learning have strong theoretical and empirical potential to enhance science and digital literacy. However, research integrating the CSP model with the DL approach within the context of Indonesian education remains very limited. Most studies have focused more on the participatory aspects of science research but have not yet thoroughly examined the measurable contributions of CSP in formal secondary education, particularly in Indonesia (Adnan et al., 2024), especially regarding curriculum integration with a Deep Learning approach in CSP learning.

This gap highlights the need to develop a learning model capable of integrating the strengths of CSP with a comprehensive and innovative deep learning approach; therefore, this study aims to analyze the impact of a CSP learning model based on a Deep Learning approach on the science and digital literacy of high school students.

## 2. Method

### 2.1. Population and Sample

The population for this study consists of all homeroom classes in the 11th grade at State High School for the 2025/2026 academic year, comprising 10 classes and 292 students. The research sample consists of 4 classes with a total of 134 students, broken down as follows: 3 experimental classes experiment I with 33 students (11 male and 22 female), experiment II with 34 students (15 male and 19 female), experiment III with 34 students (14 male and 20 female), and a control class with 33 students (15 male and 18 female).

### 2.2. Research Design and Procedures

This study is a quasi-experimental study with a non-equivalent control group design, employing a pretest-posttest control group design. Using pre-existing groups, both groups were administered a pretest, followed by the intervention, and their posttest results were then compared (Angel & Gumanoy, 2025; Stratton, 2019). The experimental group used a CSP learning model oriented toward Deep Learning principles, consisting of three treatments: CSP Experiment I, CSP Experiment II, and CSP Experiment III; the control group used a teacher-centered learning model.

The research consisted of three stages: the pre-research stage, the implementation stage, and the post-research stage. The pre-research phase involved a preliminary study, hypothesis formulation, instrument development, the creation of the Biozen Project learning website, and the validation of the learning materials. The implementation phase was conducted over four sessions in each class, with three hours of instruction (3 x 45 minutes) during the first and third sessions and two hours of instruction (2 x 45 minutes) during the second and fourth sessions. The implementation phase consisted of science literacy tests and digital literacy questionnaires, an introduction to the Biozen Project website, and the delivery of interventions in each experimental class. Additionally, data collection was reinforced through documentation of the learning process, including observations of project activities aimed at enhancing competencies (Emery et al., 2021) and the utilization of digital platforms as an integral part of the implementation of the CSP learning model. The differences in treatment between the experimental class and the control class can be seen in Table 1.


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**Table 1. Variations in Experimental Treatments for the Deep Learning-oriented CSP Learning Model and the Control Class**

| Experiment I | Experiment II | Experiment III | Control |
|---|---|---|---|
| The teacher introduces digestive system issues, and the students determine research focus. | The teacher introduces material through real phenomenon videos, and the students determine research focus. | The teacher introduces issues through popular science news, and the students determine research focus. | The teacher explains learning objectives and provides motivation. |
| The teacher guides students to develop research design (Toolkit), and experts review literature. | The teacher guides students to develop project design (Toolkit) based on video, and experts provide input. | The teacher guides students to develop research design from literature review, and experts provide input. | The teacher presents material through lectures. |
| The teacher guides schedule preparation, students create a timeline, and experts provide input. | The teacher guides schedule preparation, students create a timeline, and experts provide input. | The teacher guides schedule preparation, students create a timeline, and experts provide input. | The teacher directs students to work on the student Worksheet. |
| The teacher monitors implementation, students work in groups and report on the CSP platform. | The teacher monitors implementation, students work in groups and report on the CSP platform. | The teacher monitors implementation, students work in groups and report on the CSP platform. | The teacher guides students to collect information from teaching materials. |
| The teacher monitors progress, students report and compare results, the experts provide insight. | Teacher conduct online monitoring, students submit data and obstacles, the experts comment. | Teacher monitors interim results, the experts respond to reports to strengthen understanding. | Students present completed student worksheet in groups. |
| Teacher assesses the final report, and the students compile articles combining findings with literature. | Teacher assesses the final report, students compile reports with empirical data collected. | Teacher assesses the final report, students compile infographic reports and present in class. | The teacher evaluates student learning outcomes. |
| Teacher facilitates reflection, students connect field experience with theory. | Teacher facilitates reflection, students reflect on field learning experience. | Teacher facilitates literature-based reflection, students reflect on their experience. | Teacher gives appreciation to students. |

In this study, the researcher served directly as the teacher for both the experimental and control groups. The material covered was the digestive system, with subtopics including the organs of the digestive system, chemical and mechanical digestion processes, and digestive disorders, involving two projects: Project 1 on daily dietary patterns and Project 2 on digestive disorders. This material aligns with the CSP learning model because phenomena related to the digestive system can be directly observed through dietary patterns and lifestyle habits in the surrounding environment both at school and in the students' home environments. For example, linking digestive functions to the types of food consumed by students (such as fats, carbohydrates, and proteins) aligns with the principle that students learn through direct experience and observation in real-world contexts, fostering meaningful learning (Ares et al., 2024; Vargas et al., 2025).

## 2.3. Research Instrument

The instruments used in this study include several data collection tools designed to comprehensively measure the research variables. The science literacy and digital literacy instruments were validated by two expert validators, yielding a validity score of 4.58 (classified as valid) and a reliability of 0.945, which falls into the "very good agreement" category for science literacy; meanwhile, the digital literacy instrument showed a validity score of 4.68 (classified as valid) and a reliability of 0.986, which also falls into the "very good agreement" category. The categorization of the science literacy instrument refers to Hobri (2010), while digital literacy refers to the criteria of Papada et al. (2026).

Science literacy was measured using a pretest and posttest in the form of open-ended questions. This test was designed based on science literacy indicators referenced in (Oberbauer et al., 2021), consisting of three indicators: (1) Explaining phenomena scientifically, (2) Evaluating and designing scientific investigations, and (3) Using scientific evidence, which are collectively divided into eight sub-indicators. Digital literacy was measured using pre-test and post-test questionnaires. The questionnaires were able to elicit data directly from the research subjects regarding perceptions and attitudes that cannot be observed directly. The criteria for digital literacy skills using the questionnaire instrument, based on (Khalaisang & Yoshida, 2022), consist of four components: (1) Self-Initiation (2) Trendiness (Technological Trends), (3) Usefulness, and (4) Positive Attitude, comprising a total of 13 sub-indicators. Students' digital literacy activities are conducted through the CSP learning platform, which employs a Deep Learning-oriented approach (Biozen Project) in blended learning.

## 2.4. Data Analysis

Data analysis in this study was conducted in two main stages: descriptive and inferential analysis. Descriptive analysis was used to describe general trends in pretest and posttest scores for science literacy and digital literacy by calculating the mean, standard deviation, range, and distribution of ability categories. Next,


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inferential analysis began with normality and homogeneity tests to ensure that statistical assumptions were met. If the assumptions were met, hypothesis testing was performed using ANCOVA to determine differences in the effects between treatments, followed by a Tukey HSD test if significant differences were found. This entire analysis is designed to provide an objective and valid interpretation of the effectiveness of the Deep Learning-oriented CSP learning model.

# 3. Results and Discussion

## 3.1. Results

The effectiveness of the CSP learning model, which is based on a deep learning approach, is reflected in the improvement in students' science and digital literacy skills, as shown in the descriptive analysis presented in Table 2. Based on Table 2, it can be observed that students' digital literacy skills showed an increase between the pre- and post-intervention periods. Experimental classes I, II, and III scored higher than the control class; the average science literacy score for experimental class I was 85.95, experimental class II was 84.40, experimental class III was 83.42, while the control class was 57.56. Thus, the difference between experimental class I and the control was 28.39, the difference between Experiment II and the control group was 26.84, and the difference between Experiment III and the control group was 25.86. As for digital literacy, Experiment classes I, II, and III also scored higher than the control group. The average digital literacy score for Experimental Class I is 88.16, Experimental Class II is 87.36, Experimental Class III is 84.93, while the control class is 60.03. Thus, the difference between Experimental Class I and the control class is 28.13, the difference between Experimental Class II and the control class is 27.33, and the difference between Experiment III and the control group is 24.90.

The highest score in Experiment I was 100 and the lowest was 77.78; in Experiment II, the highest was 97.22 and the lowest was 75; in Experiment III, the highest was 91.67 and the lowest was 72.22; in the control group, the highest score was 69.44 and the lowest was 47.22 for science literacy, while for digital literacy, the highest score in Experiment I was 94. 92 and the lowest score was 81.17; for Experiment II, the highest score was 93.75 and the lowest score was 79.46; for Experiment III, the highest score was 92.63 and the lowest score was 79.75; and for the control group, the highest score was 69.53 and the lowest score was 50.38 for digital literacy. The standard deviation for the experimental groups was 6.09 for Experiment I, 5.54 for Experiment II, 5.10 for Experiment III, and 6.81 for the control group regarding science literacy, while for digital literacy, the standard deviation was 3.34 for Experiment I, 3.20 for Experiment II, 3.02 for Experiment III, and 4.53 for the control group.

Next, the frequency distribution and percentages of science literacy and digital literacy are presented based on the categories for science literacy and digital literacy in Table 3. Based on Table 3, the frequency distribution of science literacy shows that students in the experimental classes were predominantly in the very high and high categories, particularly in the CSP I class, where 22 students (66.66%) were in the very high category and 11 students (33.33%) were in the high category, compared to the CSP II and CSP III experimental classes, while the teacher-centered classes were still dominated by the moderate category, with 15 students (45.45%) in that range, down to the very low category with 11 students (33.33%). In digital literacy, all experimental classes were dominated by the very strong category. In CSP I, all students (100%) were in the very strong category. The CSP II class had 32 students (96.96%) in the very strong category and 1 student (2.94%) in the strong category. The CSP III class consisted of 30 students (88.24%) in the very strong category and 4 students (11.76%) in the strong category. Meanwhile, the teacher-centered class was mostly in the adequate category.


ISSN: 2797-3174

**Table 2. Descriptive Analysis of Science Literacy and Digital Literacy in the Experimental and Control Classes**

| Statistics | Treatment | Science Literacy | | | | Digital Literacy | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CSP I | CSP II | CSP III | Teacher Centered | CSP I | CSP II | CSP III | Teacher Centered |
| Sample Size | Pre-Treatment (Baseline) | 33 | 34 | 34 | 33 | 33 | 34 | 34 | 33 |
| Mean | | 36.36 | 36.60 | 35.36 | 31.04 | 55.50 | 50.72 | 59.16 | 55.19 |
| Highest Score | | 52.78 | 55.56 | 52.78 | 47.22 | 65.33 | 66.92 | 63.17 | 64.46 |
| Lowest Score | | 25.00 | 25.00 | 22.22 | 19.44 | 39.46 | 37.88 | 52.71 | 45.17 |
| Standard Deviation | | 7.29 | 7.63 | 7.01 | 6.55 | 6.43 | 8.48 | 2.64 | 4.87 |
| Sample Size | After Treatment (Final) | 33 | 34 | 34 | 33 | 33 | 34 | 34 | 33 |
| Mean | | 85.95 | 84.40 | 83.42 | 57.56 | 88.16 | 87.36 | 84.93 | 60.03 |
| Highest Score | | 100 | 97.22 | 91.67 | 69.00 | 94.92 | 93.75 | 92.63 | 69.58 |
| Lowest Score | | 77.78 | 75.00 | 72.22 | 47.22 | 81.17 | 79.46 | 79.75 | 50.38 |
| Standard Deviation | | 6.09 | 5.92 | 5.05 | 6.76 | 3.34 | 3.20 | 3.02 | 4.53 |

**Table 3. Frequency Distribution and Percentages of Science Literacy and Digital Literacy**

| Category | Science Literacy | | | | | | | | Category | Digital Literacy | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CSP I | | CSP II | | CSP II | | Teacher Centered | | | CSP I | | CSP II | | CSP III | | Teacher Centered | |
| | F | % | F | % | F | % | F | % | | F | % | F | % | F | % | F | % |
| Very High 86-100 | 22 | 66.66 | 14 | 41.17 | 14 | 41.17 | 0 | 0 | Very Strong 81-100 | 33 | 100 | 32 | 96.96 | 30 | 88.24 | 0 | 0 |
| High 76-85 | 11 | 33.33 | 17 | 50 | 18 | 52.94 | 0 | 0 | Strong 61-80 | 0 | 0 | 1 | 2.94 | 4 | 11.76 | 11 | 33.33 |
| Moderate 60-75 | 0 | 0 | 3 | 8.82 | 2 | 5.55 | 15 | 45.45 | Fair 41-60 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 66.66 |
| Low 55-59 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 21.21 | Weak 21-40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Very Low ≤54 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 33.33 | Very Weak 0-20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |


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Based on these results, a normality test was then conducted using the Kolmogorov-Smirnov test, which showed that the students' pretest and posttest data had a significance level (Sig.) greater than 0.05, meaning the data were normally distributed. The normally distributed data showed that the data distribution in each group was as follows: CSP Experiment I pretest 0.200 and posttest 0.200, CSP Experiment II pretest 0.082 and posttest 0.37, Experiment III CSP with a pretest of 0.070 and a posttest of 0.188, and the teacher-centered group with a pretest of 0.200 and a posttest of 0.064 for science literacy. Meanwhile, digital literacy in CSP Experiments I, II, and III had the same significance values, namely a pretest of 0.200 and a posttest of 0.200, while the teacher-centered group had a pretest of 0.074 and a posttest of 0.200. The results of the normality test for student scores were relatively good and did not show significant deviations (Habibzadeh, 2024).

Since the normality test was met, a homogeneity analysis was conducted using Levene's statistic, which showed that the significance value (Sig.) for science literacy and digital literacy was greater than 0.05 specifically, 0.215 for science literacy and 0.258 for digital literacy. This indicates that the variance of the data across groups including Experimental Groups I, II, and III as well as the control class is homogeneous. Data homogeneity indicates that the students' abilities in each group are relatively balanced. This is in line with Jiang et al. (2022), who stated that data with a significance value greater than 0.05 indicates that the homogeneous group variance meets the criteria for further analysis. Next, an ANCOVA test was conducted to determine the significant effect of the learning model on students' science literacy and digital literacy abilities, as shown in Table 4.

**Table 4. Analysis of the ANCOVA Test for Science Literacy and Digital Literacy**

| Source | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|
| Corrected Model | Science Literacy | 17943.070[a] | 4 | 4485.768 | 129.800 | .000 | .801 |
| | Digital Literacy | 18848.713[a] | 4 | 4712.178 | 374.741 | .000 | .921 |
| Intercept | Science Literacy | 31512.150 | 1 | 31512.150 | 911.834 | .000 | .876 |
| | Digital Literacy | 8316.654 | 1 | 8316.654 | 661.390 | .000 | .837 |
| Pre-test | Science Literacy | .296 | 1 | .296 | .009 | .926 | .000 |
| | Digital Literacy | 99.260 | 1 | 99.260 | 7.894 | .006 | .058 |
| Class | Science Literacy | 16321.071 | 3 | 5440.357 | 157.422 | .000 | .785 |
| | Digital Literacy | 18586.544 | 3 | 6195.515 | 492.705 | .000 | .920 |
| Error | Science Literacy | 4458.124 | 129 | 34.559 | | | |
| | Digital Literacy | 1622.110 | 129 | 12.574 | | | |
| Total | Science Literacy | 836102.616 | 134 | | | | |
| | Digital Literacy | 893867.706 | 134 | | | | |
| Corrected Total | Science Literacy | 22401.194 | 133 | | | | |
| | Digital Literacy | 20470.824 | 133 | | | | |

The Deep Learning-oriented CSP learning model has a significant effect on students' science literacy and digital literacy skills. For the science literacy variable, an F-value of 157.422 was obtained with a significance level of 0.000 ($p < 0.05$). These results indicate that there is a significant difference in science literacy skills among the experimental groups after being taught using the Deep Learning-oriented CSP learning model. Additionally, a Partial Eta Squared value of 0.785 indicates that the learning model has a large effect size on improving students' science literacy skills.

Further tests were conducted to determine whether there were significant differences between the experimental group and the control group, as shown in Table 5. Based on the results of the further test on the science literacy variable, significant differences were found between all experimental classes and the control class. Experiment I showed a mean difference of 28.166 compared to the control class, with a significance value of 0.000 (*p* < 0.05). The same pattern was observed in Experiment II and Experiment III, which had mean differences of 26.459 and 25.641, respectively, with significance values of 0.000. However, comparisons among the experimental classes showed no significant differences. The significance values between Experiment I and Experiment II, Experiment I and Experiment III, and Experiment II and Experiment III were 0.237, 0.081, and 0.568, respectively. Since these values are greater than 0.05, it can be concluded that the three experimental treatments are equally effective in improving students' science literacy.

The results of the further test on the digital literacy variable also showed significant differences between the experimental classes and the control class. Experiment I had a mean difference of 27.925 compared to the control class, with a significance value of 0.000. The mean differences for Experiment II and Experiment III were 27.813 and 26.205, respectively, with significance values of 0.000. However, no significant differences were found among the experimental classes. The significance values between Experiment I and Experiment II, Experiment I and Experiment III, and Experiment II and Experiment III were 0.901, 0.054, and 0.097, respectively. These findings suggest that all learning models applied in the experimental classes contributed relatively equally to improving students' digital literacy.


ISSN: 2797-3174

**Table 5. Post-hoc Analysis of Science Literacy and Digital Literacy**

| Dependent Variable | Parameter (I) Class | (J) Class | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|---|
| Science Literacy | Experiment I | Experiment II | 1.707 | 1.438 | .237 | -1.138 | 4.553 |
| | | Experiment III | 2.526 | 1.437 | .081 | -.317 | 5.368 |
| | | Control | 28.166* | 1.497 | .000 | 25.204 | 31.128 |
| | Experiment II | Experiment I | -1.707 | 1.438 | .237 | -4.553 | 1.138 |
| | | Experiment III | .818 | 1.429 | .568 | -2.008 | 3.645 |
| | | Control | 26.459* | 1.471 | .000 | 23.548 | 29.370 |
| | Experiment III | Experiment I | -2.526 | 1.437 | .081 | -5.368 | .317 |
| | | Experiment II | -.818 | 1.429 | .568 | -3.645 | 2.008 |
| | | Control | 25.641* | 1.493 | .000 | 22.687 | 28.594 |
| | Control | Experiment I | -28.166* | 1.497 | .000 | -31.128 | -25.204 |
| | | Experiment II | -26.459* | 1.471 | .000 | -29.370 | -23.548 |
| | | Experiment III | -25.641* | 1.493 | .000 | -28.594 | -22.687 |
| Digital Literacy | Experiment I | Experiment II | .112 | .901 | .901 | -1.670 | 1.894 |
| | | Experiment III | 1.720 | .887 | .054 | -.034 | 3.475 |
| | | Control | 27.925* | .875 | .000 | 26.193 | 29.657 |
| | Experiment II | Experiment I | -.112 | .901 | .901 | -1.894 | 1.670 |
| | | Experiment III | 1.608 | .963 | .097 | -.296 | 3.513 |
| | | Control | 27.813* | .885 | .000 | 26.062 | 29.564 |
| | Experiment III | Experiment I | -1.720 | .887 | .054 | -3.475 | .034 |
| | | Experiment II | -1.608 | .963 | .097 | -3.513 | .296 |
| | | Control | 26.205* | .903 | .000 | 24.419 | 27.991 |
| | Control | Experiment I | -27.925* | .875 | .000 | -29.657 | -26.193 |
| | | Experiment II | -27.813* | .885 | .000 | -29.564 | -26.062 |
| | | Experiment III | -26.205* | .903 | .000 | -27.991 | -24.419 |

## 3.2. Discussion

The CSP learning model is an authentic learning framework based on real-world scientific projects that connects students with their communities or social environments (Lusse et al., 2022; Ballard et al., 2024; Pizzolato & Zuji, 2022; Adnan et al., 2024), thereby encouraging student engagement to enhance interest, scientific identity, and the perception of science's relevance to life (Olivo et al., 2024; Alfaro et al., 2024). These characteristics align with the Deep Learning approach in Pancasila Education, defined as a learning approach that integrates the principles of mindful learning, meaningful learning, and joyful learning. These principles foster students' ability to understand, apply, and reflect on the knowledge they acquire (Komalasari et al., 2025). The CSP learning model, oriented toward Deep Learning, is integrated with an online platform that provides space for exploration, problem-solving, collaboration, and independent use of technology (Adnan et al., 2024; Philips et al., 2018). These conditions foster motivation, meaningful independent learning, and improved science and digital literacy (Sholahuddin et al., 2023; Susilawati et al., 2025).

The results of the study indicate that instruction in the three experimental classes yielded better outcomes than teacher-centered instruction in terms of students' science literacy and digital literacy skills. The magnitude of the impact of the Deep Learning-oriented CSP instructional model on these literacy skills is supported by the effect size values obtained. The ANCOVA analysis showed a Partial Eta Squared value of 0.785 for science literacy and 0.920 for digital literacy, both of which fall into the large effect category. The high effect size indicates that the improvement in science and digital literacy is not only statistically significant but also has strong practical implications for the learning process. This reflects that during the learning process, students engaged in discussions and collaboration with informants, experts, and group peers, providing them with opportunities to exchange perspectives and construct meaning, thereby deepening their understanding of the material (Andrews et al., 2023; De Olievera et al., 2024; Smith et al., 2022). Furthermore, the use of digital technology or online citizen science through material exploration and project content creation helps develop communication and digital literacy skills (Aristeidou & Herodotou, 2020). Co-created extreme citizen science projects, which involve students from the problem-identification stage through to drawing conclusions, are considered to have great potential for creating a learning process that is meaningful, contextual, and grounded in students' real-world experiences (Bruckermann et al., 2022; Pizzolato & Tsuji, 2022; Ballard et al., 2024).

Conventional learning tends to focus on one-way delivery of material, resulting in relatively low student engagement. One-way information causes students' attention to wane, their interest to wane, and the practical application of concepts to decrease (Zen & Ariani, 2022; Martin et al., 2024). In contrast, CSP provides space for students to learn through real-world experiences, work collaboratively, and solve contextual problems. Additionally, students connect their existing foundational knowledge with new knowledge gained through information obtained from interview informants, experts, or literature reviews, thereby fostering meaningful


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learning. Hsbollah & Hasan (2022) state that meaningful learning is defined as the substantive integration of new knowledge into an existing knowledge structure, not merely memorization.

The significant improvement in science literacy in the experimental class compared to the control class indicates that student engagement in scientific activities is a key factor in the development of conceptual understanding. Students conducted a digestive system project focusing on dietary patterns related to mechanical and chemical digestive enzymes and digestive system disorders occurring in their surroundings, both at home and at school. Additionally, prior to the project, students analyzed the project's problems by engaging a medical expert in Experimental Class I, watching videos of real-world phenomena in Experimental Class II, and reviewing popular science news in Experimental Class III. These project activities encourage students to understand the concepts of the digestive system, analyze information obtained through science-based interviews and observations, and relate it to real-life phenomena supported by experts, including general practitioners, nutritionists, and biology professors, as well as theoretical studies from literature obtained by the students. The findings are reported in the form of a simple scientific article for Experiment I, a project report for Experiment II, and an infographic for Experiment III. Through scientific project-based learning, students are able to identify emerging issues in society, analyze them, and discuss them systematically, thereby developing their data-driven reasoning skills and ability to construct scientific arguments (Mahmudah et al. 2022; Faisal & Martin, 2020).

This aligns with constructivist theory, which emphasizes that knowledge is constructed through direct experience and interaction with the environment (Marougkas et al., 2023; Adnan et al., 2024). CSP learning oriented toward a deep learning approach encourages students to act as active agents in the learning process, enabling them to develop the ability to explain phenomena scientifically, evaluate investigations, and utilize scientific evidence more deeply. According to Singt et al. (2022), knowledge is formed through an individual's engagement with real-world conditions, authentic situations, and problem-solving processes within a social context. Activating relevant prior knowledge that aligns with new concepts can facilitate the integration of information, help correct misconceptions, and foster a more systematic and in-depth knowledge structure (Brod, 2021; Adnan et al., 2025; Brand et al., 2025). Furthermore, the syntactic stages of the CSP model (Adnan et al., 2024), combined with three principles of Deep Learning, foster higher-order cognitive processes that emphasize students' ability to connect prior knowledge with new knowledge, engage in critical thinking, and solve complex problems rather than merely memorizing facts (Weng, 2023; Sølvik & Glenna, 2022). This is also consistent with Bruner's theory, which states that students should not simply receive material in its final form but should instead be encouraged to organize and discover connections between pieces of information (Khoiriyah & Murni, 2021; Sahira & Ismail, 2024).

Improvements in students' digital literacy are also closely linked to the integration of technology at every stage of CSP learning. Students are engaged in using digital platforms to access information, collaborate, upload data, and present the results of their projects (Adnan et al., 2024). This aligns with Ateş & Köroğlu (2024), who noted in their study that learning outcomes and motivation increase when online media are integrated into project-based learning compared to traditional approaches. These activities directly develop various aspects of digital literacy, such as the ability to evaluate information, online communication, and the production of digital products. The implementation of the Deep Learning-oriented CSP learning process utilizes the Biozen Project platform to access digestive system materials, consult experts, collect project reports, and track students' project locations. Technology in CSP learning functions not merely as a tool but as an integral part of the learning process. This leads to a more intensive and sustainable improvement in digital literacy. According to Wang & Fan (2025), the appropriate use of technology in creative learning has the strongest impact on improving digital literacy. Guyen & Habok (2022) also note that 21st-century skills education focuses on developing students' skills as users and producers of information, as well as enhancing their social and intellectual abilities in the context of digital collaboration related to digital literacy.

The absence of significant differences among the experimental groups indicates that the effectiveness of CSP is consistent. This indicates that the Deep Learning-oriented CSP model offers flexibility in implementation and continues to deliver optimal results even when applied across various learning contexts, including different project themes and project outputs (Aripin et al., 2023; Bela et al., 2016; Pizzolato & Tsuji, 2022). In line with this, based on the research results, the learning model—which is grounded in the same process—supports the claim that variations in project tasks tend not to result in significant differences in achievement across classes, as long as the quality of instructional syntax is maintained, students remain engaged in authentic inquiry, data analysis, collaboration, deep contextual problem-solving, science literacy, and digital literacy (Krajcik et al., 2022; Guo et al., 2020). The Deep Learning-oriented CSP learning model not only enhances conceptual understanding, science literacy, and digital literacy but also develops 21st-century skills, such as critical thinking, collaboration, and communication. The integration of project-based learning, authentic scientific experiences, and the use of digital technology enables CSP to significantly and sustainably improve students' literacy.


ISSN: 2797-3174

### 3.3. Implications

The results of the study indicate that the Deep Learning-oriented CSP learning model has the potential to serve as an effective alternative for strengthening students' science and digital literacy. The higher achievement levels observed in all experimental classes compared to teacher-centered instruction highlight the importance of learning approaches that engage students through inquiry-based activities, contextual problem-solving, collaboration, and the use of technology. Furthermore, the absence of significant differences among the experimental classes suggests that the Deep Learning-oriented CSP model offers implementation flexibility and remains effective even when applied with variations in themes, learning resources, and project outcomes. These findings underscore the urgency of integrating authentic scientific projects and digital technology in learning to develop students' literacy competencies, as well as to support the implementation of Deep Learning and the strengthening of 21st-century skills in schools.

### 3.4. Limitations

This study has several limitations that should be considered when interpreting the results: the application of the CSP learning model, which is oriented toward a deep learning approach, was focused solely on the digestive system, meaning that the effectiveness of the CSP model for other biology topics cannot yet be broadly generalized. Furthermore, this study was conducted at only one high school; thus, the relatively homogeneous characteristics of the students, learning environment, and academic culture may limit its application in different educational contexts. Finally, the study focused only on measuring science literacy and digital literacy, so it has not comprehensively examined the influence of the Deep Learning-oriented CSP learning model on other 21st-century competencies such as students' critical thinking, creative thinking, communication, and collaboration skills.

## 4. Conclusion

This study shows that the CSP learning model, which is based on a deep learning approach, is effective in significantly improving students' science literacy and digital literacy compared to conventional learning. This improvement is evident in students' ability to understand scientific phenomena, evaluate evidence-based information, solve contextual problems, and use digital technology critically and responsibly. Statistical analysis confirms that the learning model has a significant impact, with a large effect size, on science literacy and digital literacy. The effectiveness of CSP learning is closely tied to students' active engagement in authentic scientific projects, particularly regarding digestive system topics—such as dietary patterns and digestive disorders—found in their own environments. This fosters processes of observation, data collection, collaboration, investigation, and technology-based scientific communication. The integration of the principles of mindful, meaningful, and joyful learning in the Deep Learning approach helps create a more in-depth, contextual, and learner-centered learning experience while connecting learning materials to real life. In addition to strengthening science and digital literacy, this model also contributes to the development of 21st-century skills, particularly critical thinking, creativity, collaboration, and communication. This learning model is recommended for widespread implementation across various subjects and educational levels to enhance the quality of meaningful learning.

## Author Contributions

All authors contributed equally to this paper. All authors have read and approved the final manuscript.

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## Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

## Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

## Declaration on AI Use

AI were used only to improve readability and language under strict human oversight; no content, ideas, analyses, or conclusions were generated by AI.


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