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https://doi.org/10.3390/educsci15040448

This is the Published Version of the final output.

UWL repository link: https://repository.uwl.ac.uk/id/eprint/13683/

education sciences

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Article

The Impact of Integrated Project-Based Learning and Flipped Classroom on Students' Computational Thinking Skills: Embedded Mixed Methods

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Abstract: Computational thinking skills among high school students have become a global concern, especially in the context of the ever-evolving digital education era. However, the attention given by teachers to this skill during mathematics instruction has not been a priority. This study aims to evaluate and explore the impact of project-based learning (PBL) integrated with flipped classroom on high school students' computational thinking skills in mathematics. The research design employed a mixed-method approach with a quasi-experimental, nonequivalent pre-test post-test control group design. The experimental group (46 students) and control group (45 students) were selected through simple random sampling from 12th-grade science students. Data were collected through tests, questionnaires, and in-depth interviews, using instruments such as computational thinking skills assessment questions, questionnaires, and interview protocols. Quantitative data analysis was performed using SPSS Version 26 for *t*-tests and ANOVA, while qualitative analysis was conducted using ATLAS.ti with an abductive-inductive and thematic approach. The findings indicate that PBL integrated with flipped classrooms significantly improved students' decomposition, pattern recognition, and abstraction skills. The implementation of PBL, integrated with a flipped classroom, created an interactive learning environment, fostering active engagement and enhancing students' understanding and skills in solving mathematical concepts. Although there was an improvement in algorithmic thinking skills, some students still faced difficulties in developing systematic solutions. The results of this study suggest that further research could explore other methodologies, such as grounded theory and case studies integrated with e-learning, and emphasize visual analysis methods, such as using photo elicitation to explore thinking skills.

Keywords: project-based learning; flipped classroom; computational thinking skills; mathematics learning; learning technology

Academic Editors: Mi Yeon Lee and Kelum Gamage

Received: 27 January 2025
Revised: 29 March 2025
Accepted: 31 March 2025
Published: 2 April 2025

Citation: Fitrah, M., Sofroniou, A., Setiawan, C., Widihastuti, W., Yarmanetti, N., Jaya, M. P. S., Panuntun, J. G., Arfaton, A., Beteno, S., & Susianti, I. (2025). The Impact of Integrated Project-Based Learning and Flipped Classroom on Students' Computational Thinking Skills: Embedded Mixed Methods. *Education Sciences*, *15*(4), 448. https://doi.org/10.3390/educsci15040448

1. Introduction

The 21st century education demands learners to develop higher-order thinking skills essential for adapting to an increasingly complex and dynamic world. Transformations in education now require more innovative pedagogical approaches that not only facilitate knowledge transfer but also promote the development of thinking skills such as computational thinking. Amid the evolving teaching practices, the project-based learning (PBL) model has emerged as an effective approach that can be further optimized when integrated with the flipped classroom concept. This combination encourages not only active and collaborative learning but also provides students with opportunities to cultivate 21st-century skills (Dong et al., 2024).

Previous studies have provided empirical evidence on the effectiveness of PBL and flipped classrooms in education. For instance, research by Li and Tu (2024) demonstrated that integrated PBL significantly enhances students' creative thinking skills, engagement, and collaboration (AlAli, 2024; Maros et al., 2021; Rehman et al., 2024). In mathematics education, PBL creates a more positive learning environment and improves student outcomes (Holmes & Hwang, 2016; Rehman et al., 2024). This effectiveness stems from maximizing students' roles, such as collaborating, coordinating, communicating, leading, practicing, and exerting effort in integrated design project activities (Çakiroğlu & Erdemir, 2018).

Through direct and in-depth investigations and authentic interviews conducted over a semester (six months) with teachers in schools, we observed that traditional teacher-centered methods frequently fail to equip students with the skills required by advancements in science and technology, such as computational thinking skills. Traditional teaching often focuses excessively on rote memorization and rigid, procedural problem-solving approaches, which do not encourage students to develop critical and innovative thinking. Furthermore, the utilization of technology as a learning tool is underwhelming, and many teachers we observed lacked proficiency in using technology. Consequently, the presence of technology in schools often serves as a facade rather than a reality in mathematics education. This complexity underscores the need for more in-depth research. Findings from Charbonneau-Gowdy et al. (2023) revealed that, in the past two years (2021–2022), computational thinking skills, active learning, and the use of technology are closely interconnected. The meta-analysis by Alonso-García et al. (2024) indicates that the development of educational practices emphasizing technology is predominantly observed in Asia, yet it does not specifically include Indonesia. This finding highlights the importance of further research on computational thinking skills in Indonesia, particularly by integrating technology-based learning models. Such research has the potential to significantly contribute to a more critical transformation of education in addressing complex problem-solving challenges (Alonso-García et al., 2024).

Despite these field observations, we also reviewed challenges identified by previous researchers underpinning PBL studies. For instance, Rijken and Fraser (2023) highlighted a decline in student engagement in mathematics learning during the transition from primary to secondary school, often due to less favorable classroom environments and curriculum changes. This decline in engagement adversely affects students' performance in mathematics exams (Craig & Marshall, 2019). Moreover, students tend to be passive, struggle with independent learning, and perceive mathematics as difficult, boring, or uninteresting (Remijan, 2017).

In light of these issues, the integration of PBL with flipped classrooms emerges as one of the most promising approaches in the era of technology. This integration enables students to engage in independent learning outside the classroom and subsequently apply and discuss their understanding in more dynamic and interactive face-to-face sessions. This aligns with the ideas presented by Charbonneau-Gowdy et al. (2023), who emphasized flipped classrooms as an innovative teaching method involving new explorations. Furthermore, Egara and Mosimege's (2023) research illustrated that this approach improves students' achievement, interest, and attitudes in mathematics learning (Tekin &

Sarıkaya, 2020), fostering interactive and active environments for both individual and group learning. Additionally, Gondal et al. (2024) reported significant improvements in students' average scores and high satisfaction levels with flipped classrooms (Deng et al., 2023; Egara & Mosimege, 2023). Specifically, flipped classroom designs with instructional videos effectively enhance knowledge retention (Shen, 2024).

Flipped learning, when combined with active methodologies such as project-based learning, significantly improves students' critical thinking, creativity, and collaboration skills, particularly in secondary education (Bolivar et al., 2023; Hossein-Mohand et al., 2021; Mohamed et al., 2019). According to the framework designed by Cubric and Tripathi (2009), the collaboration of these two methods fosters personalized and collaborative online learning spaces. Research by Zarouk et al. (2020) supported this, showing that PBL implementation within flipped classrooms enhances students' motivation, strategic planning, and self-monitoring skills, especially when students actively engage with peers (Dinh & Phuong, 2025; Liu et al., 2024; Pokhrel et al., 2024). However, a critical gap remains in both the literature and our investigations: the combination of PBL and flipped classrooms in developing computational thinking skills has not been extensively explored. Computational thinking involves a set of skills, including problem decomposition, pattern recognition, abstraction, and algorithm design, which are foundational for effective problem-solving across disciplines. Through project-based learning, students have opportunities to tackle complex problems, decompose them into manageable components, design efficient solutions, and test hypotheses.

This study aims to explore the impact of PBL integrated with flipped classroom on the development of computational thinking skills among senior high school students studying geometric transformations in Grade 12. We believe that this study will provide significant contributions to the mathematics education literature by offering empirical evidence that strengthens the argument that this approach not only enhances computational thinking skills but also prepares students for future challenges aligned with technological advancements in the workplace. By integrating PBL and flipped classrooms, we aim to reinforce and recommend the implementation of a learning model that promotes active and independent learning, fosters computational thinking abilities, and enhances students' skill sets. This research is crucial not only in the local context but also has global implications for developing education that is more responsive to contemporary needs.

Based on the theoretical issues and direct observations, this research seeks to answer the following questions: Is there a difference in computational thinking skills between students taught using PBL integrated with a flipped classroom and those taught using PBL alone? How does the integrated PBL and flipped classroom process influence students' computational thinking skills? From these research questions, the hypotheses are as follows:

H_1: *There is a difference in decomposition skills between students taught using PBL integrated with flipped classroom and those taught using PBL.*

H_2: *There is a difference in pattern recognition skills between students taught using PBL integrated with flipped classroom and those taught using PBL.*

H_3: *There is a difference in abstraction skills between students taught using PBL integrated with flipped classroom and those taught using PBL.*

H_4: *There is a difference in algorithmic thinking skills between students taught using PBL integrated with flipped classroom and those taught using PBL.*

2. Literature Review

2.1. Project-Based Learning in Mathematics Instruction

Project-Based Learning (PBL), as a student-centered approach, plays a significant role in enhancing 21st-century skills such as computational thinking and problem-solving within mathematics education. PBL emphasizes that meaningful learning occurs when students actively construct their knowledge through experience and interaction. Students are encouraged to connect abstract concepts with real-world situations through challenging and relevant projects (Nayak et al., 2024; Singha & Singha, 2024). PBL promotes the completion of projects that require data analysis, solution creation, and presentations, fostering active engagement and providing a learning experience that significantly differs from conventional teaching methods (Holmes & Hwang, 2016).

Since its introduction, the concept of PBL has evolved alongside the integration of technology in education. Meyer et al. (1997) emphasized that PBL engages students in solving real-world problems that require them to apply mathematical knowledge in meaningful contexts. Kim and Lee (2002) highlighted that technology not only serves as a tool but also as a pivotal element that deepens the reflection process in PBL, enhancing students' learning experiences. Moreover, Gibson et al. (2002) argued that technology, particularly ICT, plays a crucial role in supporting the learning process in PBL, allowing students to utilize software and the internet for research and collaboration. However, the implementation of PBL in mathematics instruction faces significant challenges. Rijken and Fraser (2023) highlight the necessity for strong facilitation skills from teachers to accommodate long-term projects. Furthermore, constraints such as limited resources and lack of teacher training are significant concerns (My Nguyen et al., 2024). Nevertheless, PBL integrates collaboration and knowledge sharing through online learning communities, creating an enriched learning ecosystem (Kramer et al., 2007). Moss (2000) further emphasized that technology-supported PBL creates a dynamic and interactive learning environment, which not only enhances academic content skills but also prepares students to face real-world challenges by using digital tools effectively.

The concept of PBL has been widely applied across countries, with an emphasis on using technology to support more authentic and relevant learning. Erstad (2002) noted that in Norway, PBL combined with technology enables students to develop collaborative skills, critical thinking, and the ability to integrate knowledge from various sources. Blumenfeld et al. (1991) and Krajcik et al. (1994) also argued that PBL is not just about completing projects but also about supporting the learning process through active engagement and providing the necessary support to ensure its successful implementation in classrooms. Specifically, the use of digital technology in PBL further expands access and facilitates inclusive learning. Ndiung and Menggo (2024) underline PBL's potential in creating contextual and relevant learning environments, though it requires further enhancement.

2.2. Flipped Classroom with Active Learning

The flipped classroom is an instructional method that transforms traditional teaching models by providing foundational content for students to study independently outside of class, using digital technologies such as videos or reading materials, before engaging in integrated activities like discussions and problem-solving in class. This model allows class time to be used more efficiently for deepening complex concepts and fostering collaborative learning, particularly in mathematics instruction (Isabel Santos & Serpa, 2020). Bergmann and Sams (2012) highlighted that flipped learning enhances student engagement by shifting direct instruction outside of class, allowing more opportunities for active learning and deeper interaction. Tucker (2012) further described this model as an approach where instructional content is accessed beforehand through digital resources, enabling students to maximize in-class time for collaboration and problem-solving. Research shows that this approach significantly increases student engagement, as students not only memorize formulas but also develop critical thinking skills and the ability to apply concepts in real-world contexts (Fernández-Martín et al., 2020).

The flipped classroom approach can also be adapted to support various active methodologies that integrate technology. Students learn material independently through videos, followed by critical exploration and interactive activities in class, which deepens conceptual understanding (Fredriksen et al., 2024). This approach does not always have to be complicated, as shown by Patterson et al. (2018), who found that minimal preparation, such as reading materials before class, is still effective. Kong (2014) emphasized that flipped learning fosters information literacy and critical thinking by integrating domain knowledge learning in digital classrooms, supporting students in active and inquiry-based learning. See and Conry (2014) also demonstrated how flipped classrooms enhance student engagement by utilizing digital content for pre-class preparation, freeing up class time for case studies and collaborative projects. Furthermore, integrating the flipped classroom with technology and scaffolding yields significant results. For example, the use of learning management systems facilitates independent learning and provides relevant formative feedback (Awi et al., 2024).

A flipped classroom model supported by social learning communities fosters deeper interaction, where collaboration and instant feedback accelerate the learning process (Wang, 2024). A meta-analysis by Gong et al. (2023) also demonstrates that this approach is significantly more effective than traditional methods in improving student academic performance, with activities that link home and classroom learning, such as quizzes and group discussions, reinforcing student learning outcomes. Clark (2015) further confirmed that the flipped classroom model positively impacts student engagement and academic performance, particularly in mathematics instruction. These findings reinforce that flipped classrooms not only support academic achievement but also enhance student autonomy and engagement in the learning process.

2.3. Computational Thinking Skills and Their Impact on Mathematics Instruction

Computational thinking skills are a set of cognitive abilities that are crucial in modern mathematics instruction, including problem decomposition, pattern recognition, abstraction, and algorithm design. Sung et al. (2017) explain that integrating these skills into mathematics instruction aims to break down complex problems into simpler components and design systematic algorithmic solutions. This approach, which also includes the use of embodied cognition methods, connects physical activity with abstract concepts, strengthening students' mathematical understanding and programming skills (Sung & Black, 2020). In practice, these skills equip students with explicit processes for thinking and acting like computer scientists, which are relevant for solving 21st-century problems. Weintrop et al. (2015) emphasize that these skills encompass data processing, modeling, and simulation, which train students to analyze information, make data-integrated decisions, and understand phenomena through simulation.

Meanwhile, the use of visual programming tools such as Scratch introduces students to algorithmic principles in an accessible and engaging way, encouraging collaborative and exploratory problem-solving in mathematics (Rodríguez-Martínez et al., 2019). Integrated technology approaches, such as computer-based math games, have also been shown to enhance students' computational thinking skills. Soboleva et al. (2021) explain that these games not only motivate students but also promote systematic and algorithmic thinking, which is essential in mathematics (del Olmo-Muñoz et al., 2023). Moreover, Durak and Saritepeci (2018) found that students' academic success in mathematics significantly influences their computational thinking skills, highlighting the importance of a cognitive approach to learning. Ersozlu et al. (2023) add that authentic and relevant learning experiences strengthen the application of these skills.

3. Methods

3.1. Research Design

This study employs a mixed-method embedded design (Creswell, 2014), with a quasi-experimental approach and qualitative descriptive methods. The aim is to explore the comprehensive implementation of PBL integrated with the flipped classroom approach by teachers in mathematics instruction. The rationale for choosing this research design is that the combination of quantitative and qualitative data provides a more critical emphasis compared to a single approach. Moreover, identifying the influence and testing are complex tasks. Quantitative data will serve as the basis for generalizing findings, while qualitative data will support these generalizations. Using the mixed-method embedded design, we analyze quantitative data first and support these findings with qualitative research results.

The quasi-experimental approach uses a nonequivalent pre-test post-test control group design. In this design, both the experimental and control groups are given a pre-test to measure their initial conditions before the treatment, followed by a post-test to measure the outcomes after the treatment. The experimental group receives instruction using the PBL model integrated with the flipped classroom, while the control group follows PBL.

3.2. Population and Sample

3.2.1. Quantitative

The population for this study consists of 171 twelfth-grade students in the Science Program at a senior high school, from six classes. The selection of this school was based on its accessibility and the limited technological resources supporting learning, such as a school internet quota of only 30 Mbps per school. Additionally, the learning environment was predominantly conventional, and the teacher's creativity in integrating other learning models was weak pedagogically. The sample for this study is 91 students (45 in the control group and 46 in the experimental group), selected using simple random sampling to give every class in the population an equal chance of being chosen. This technique was chosen to avoid selection bias and improve the external validity of the study.

3.2.2. Qualitative

For the qualitative phase, the researcher used theoretical sampling. Theoretical sampling involves selecting participants who can provide relevant information to develop or test the emerging theory. The sample was chosen based on student activity during the teaching and learning process and their final grades. A total of 6 female and 4 male students were selected based on their achievement of the minimum standard score ($\geq$75) and engagement. The qualitative sample is anonymized to protect student identities. See Table 1.

Table 1. Qualitative sample.

Initial	Gender	Age	Activity Level	Score
Creswel	Male	18 Years	Active	80.00
Albert	Male	18 Years	Active	80.00
Donald	Male	17 Years	Active	80.00
Joseph	Male	18 Years	Active	85.00
Charmaz	Female	18 Years	Active	85.00

Table 1. *Cont.*

Initial	Gender	Age	Activity Level	Score
Collins	Female	17 Years	Less Active	80.00
Cohen	Female	16 Years	Less Active	75.00
Donna	Female	18 Years	Less Active	80.00
Patricia	Female	16 Years	Active	85.00
Katy	Female	17 Years	Active	85.00

3.3. Techniques and Instruments for Data Collection

The data in this study were collected using three main instruments: tests (pre-test and post-test), questionnaires, and interviews. The pre-test and post-test were used to measure computational thinking skills in transformation geometry, focusing on four main dimensions: decomposition, pattern recognition, abstraction, and algorithmic thinking. The pre-test was administered before the intervention to assess students' initial understanding of the material to be taught, while the post-test was given after the intervention to evaluate improvements in students' thinking skills. The pre-test was conducted in the first session, and the PBL intervention integrated with the flipped classroom was carried out from the second session to the eighth session (seven weeks). The post-test was then administered in the eighth session, i.e., the eighth week. Therefore, the time span between the pre-test and post-test was eight weeks.

The test consisted of 15 questions in multiple-choice, short-answer, and problem-solving formats. These questions were designed with varying levels of difficulty to explicitly measure the four dimensions of computational thinking skills. Decomposition was assessed through students' ability to break down complex problems into smaller parts. Pattern recognition examined the process of students recognizing patterns or similarities in mathematical problems. Abstraction measured students' ability to filter out irrelevant information and focus on the details necessary for problem-solving. Meanwhile, algorithmic thinking assessed students' ability to design systematic solutions and logical steps to solve problems.

The development of test items was based on the Basic Competencies and Competency Achievement Indicators established in the Regulation of the Minister of Education and Culture of the Republic of Indonesia Number 37 of 2018 concerning Core Competencies and Basic Competencies of Subjects in the 2013 Curriculum for Primary and Secondary Education levels. Table 2 presents the test blueprint, which outlines the relationship between basic competencies, competency achievement indicators, test indicators, the level of computational thinking being measured, and the number of questions included in the test.

An example of a test question used to measure students' CT skills is provided below. This question represents various CT levels, including decomposition, pattern recognition, abstraction, and algorithmic thinking, as reflected in problem-solving processes, transformation pattern identification, filtering relevant information, and systematically structuring a solution.

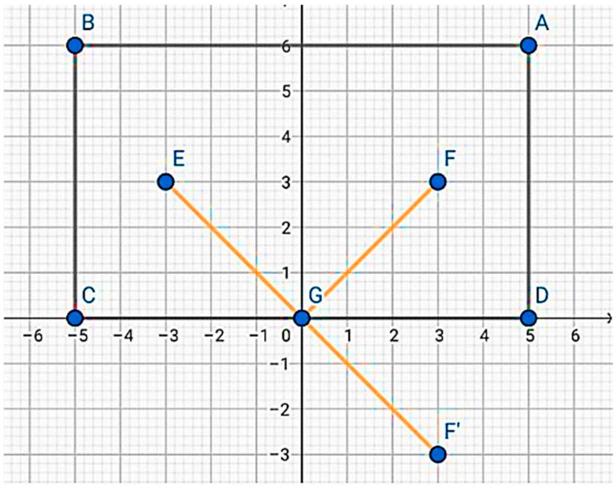
Table 2. Computational thinking test.

Basic Competency	Competency Achievement Indicator	Test Indicator	CT Level	Number of Questions
Analyzing and comparing transformations and compositions of transformations using matrices	Identifying transformation matrices (reflection) at point $O(0,0)$	Given point $A(x,y)$, students determine the reflection transformation matrix at point O(0,0) and the shadow coordinates.	Decomposition	2 (1 multiple choice, 1 Essay)
	Identifying transformation matrices (reflection) on the x-axis	Given point $A(x,y)$, students determine the reflection matrix on the x-axis and explain the changes in coordinates.	Pattern Recognition	2 (1 multiple choice, 1 Essay)
	Identifying transformation matrices (reflection) on the y-axis	Given point $A(x,y)$, students determine the reflection matrix on the y-axis and identify the pattern differences compared to the reflection on the x-axis.	Pattern Recognition	3 (2 multiple choice, 1 Essay)
	Determining the shadow of a transformation composition (reflection) using matrices	Given a point and two consecutive reflection transformations, students determine the final shadow using the composition transformation matrix.	Abstraction	4 (2 multiple choice, 1 Short Answer, 1 Essay)
Solving problems related to geometric transformation matrices (translation, reflection, dilation, and rotation)	Solving problems involving transformation (reflection)	Students are given a real-world problem requiring the application of the reflection concept in problem-solving.	Algorithmic Thinking	4 (2 multiple choice, 1 Short Answer, 1 Essay)

Example Question:

A rectangular billiard table has four corner points: $A(5,6), B(-5,6),\ C(-5,0)$ and $D(5,0)$. A ball is located at point $E(-3,3)$ and is hit towards another ball positioned at point $F(3,3)$. However, before reaching the ball at point F, the ball must first bounce off side CD of the billiard table. Determine the coordinates of the reflection point of the ball on side CD before reaching point F.

Solution:



The billiard table is a rectangle ABCD, with the ball at $E(-3,3)$ and aimed at hitting ball $F(3,3)$ after bouncing on side CD. To determine the target point on CD, we first find the reflection of point $F(3,3)$ with respect to $CD(x-axis)$, which is $F'(3,-3)$. Next, we determine the intersection of the line connecting $E(-3,3)$ and $F'(3,-3)$ with the line $CD(y=0)$. The equation of line EF' is $y=-x$. Substituting $y=0$ gives $x=0$, so the intersection point is $(0,0)$. Therefore, the target point where the ball will bounce off side CD before reaching $F(3,3)$ is $(0,0)$.

Student test scoring was aligned with the characteristics of each question type to ensure an effective measurement of computational thinking skills. The assessment included multiple-choice, short-answer, and essay questions, each with specific scoring criteria (see Table 3). The final scores were computed and normalized to a 0–100 scale.

Table 3. Scoring criteria for computational thinking assessment.

Question Type	CT Dimension Assessed	Scoring Criteria	Max Score
Multiple-Choice	All CT dimensions	1 = Correct. 0 = Incorrect.	1
Short-Answer	Abstraction, Algorithmic Thinking	3 = Correct and structured problem-solving steps. 2 = Minor inaccuracies in problem-solving steps. 1 = Most steps are incorrect. 0 = No problem-solving steps written.	3
Essay	All CT dimensions	90–100 = Deep analysis, logical solution, systematic approach. 70–89 = Mostly logical, minor errors in reasoning or structure. 50–69 = Partial understanding, significant logical or procedural errors. <50 = Lacks conceptual understanding, unsystematic response.	100

Additionally, the questionnaire was used to measure students' responses to the PBL method integrated with the flipped classroom and the development of their computational thinking skills. The questionnaire consisted of 15 statements developed based on computational thinking theory and previous research on assessing computational thinking in mathematics education and technology. The statements in the questionnaire were arranged in a Likert scale with five response levels, ranging from strongly disagree to strongly agree, to capture a deeper variation in students' understanding and experiences. Each item in the questionnaire directly represented one of the four dimensions of computational thinking being measured. The questionnaire was administered in Google Forms format and completed by students under the supervision of the teacher.

Furthermore, interviews were conducted to gain deeper insights into students' experiences during the learning process and the challenges they faced in computational learning. The interviews were conducted after the lessons, considering students' activities and the learning outcomes obtained. The interview process lasted between 45 and 82 min with a semi-structured approach. The duration was determined based on the accumulated time students spent responding to questions guided by their answers in the essay and short-answer sections. The interviews extended up to 82 min as, at this point, responses met the criteria, and response saturation was reached. The interview protocol consisted of three main themes: challenges in computational thinking, students' involvement in problem-solving strategies, and their reflections on the teaching methods used.

To ensure scoring reliability, both the researcher and the mathematics teacher independently evaluated student responses. Any discrepancies, particularly in essay and short-answer questions, were resolved through discussion and consensus.

The total score from essay questions was normalized to a 0–100 scale. Based on the final accumulated test scores, students were selected for qualitative interviews to ensure representation across different performance levels (see Table 1).

3.4. Validity and Reliability of the Instruments

To ensure the reliability and validity of the instruments, we conducted a comprehensive validity and reliability assessment prior to their use in data collection. The validity of the instruments was assessed through two main approaches: content validity and construct validity. Content validity was evaluated by analyzing the alignment of each test item, questionnaire statement, and interview protocol with the competencies outlined in the curriculum. Construct validity was established through an expert review process involving three experts in the fields of learning models, mathematics education, and educational technology, all of whom hold the academic rank of Senior Lecturer and have published scholarly works in the relevant fields. Additionally, the experts provided feedback on the clarity, difficulty level, and relevance of the items in relation to the four dimensions of CT. Based on evaluations by the three experts, the average Aiken's V value was 0.83, indicating a high level of validity. Reliability was tested using Cronbach's Alpha to ensure the internal consistency and dependability of the instruments. The results of the reliability test are presented in Table 4.

Table 4. Results of instrument validity and reliability tests.

Skill	Cronbach's Alpha
Decomposition	0.94
Pattern recognition	0.86
Abstraction	0.83
Algorithmic thinking	0.91

3.5. Data Analysis Techniques

Data analysis was carried out in several stages to ensure the validity and accuracy of the research results. First, a normality test using Kolmogorov–Smirnov was conducted to check if the data were normally distributed (see Table 5). For normally distributed data, parametric statistics such as *t*-tests and ANOVA were used. Second, a homogeneity test using Levene's test was conducted to ensure that the variance between groups was homogeneous, which is a prerequisite for further analysis.

Table 5. Results of normality tests.

Category	**Control**				**Experiment**			
	V1	V2	V3	V4	V1	V2	V3	V4
N	45				46			
Exact Sig. (2-tailed)	0.22	0.53	0.251	0.17	0.25	0.51	0.28	0.35

Based on the results of the normality test using the Exact Sig. (2-tailed) values, all variables in the control and experimental groups showed values greater than 0.05. Therefore, it can be concluded that the data are normally distributed. Thus, the assumption of normality is met, and we used parametric statistical approaches, such as *t*-tests and ANOVA, for further analysis to answer the research questions. All these analyses were conducted using SPSS version 26. In addition, qualitative data analysis in this study was conducted using ATLAS.ti version 24, employing thematic analysis with abductive (deductive) reasoning. The analysis using ATLAS.ti included 87 codes, 8 categories, and 2 themes with 210 quotations (see Figure 1).

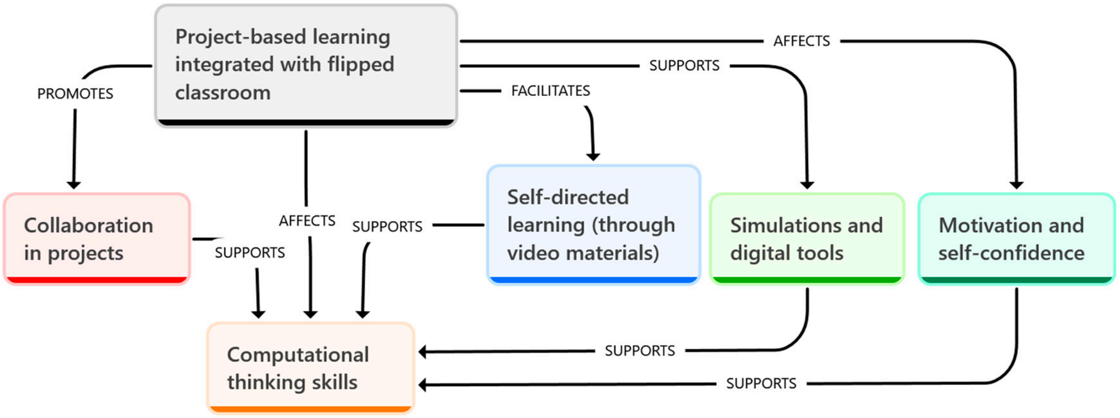


Figure 1. Contribution of integrated PBL and flipped classroom to students' computational thinking skills.

3.6. Hypothesis Testing

This study used two main statistical methods: *t*-test and ANOVA. The *t*-test was used to compare the means between the control and experimental groups. This test aimed to determine whether there was a significant difference in computational thinking skills between the two groups. If the *t*-test results showed a *p*-value < 0.05, the difference would be considered significant. ANOVA was used to examine the overall effect of the integrated PBL and flipped classroom method on students' computational thinking skills. With ANOVA, the researcher can determine whether the treatment had a significant overall effect. If the calculated F-value is greater than the F-table value, the null hypothesis (H0) is rejected, indicating that the integrated PBL and flipped classroom method has a significant effect. The *t*-test was used because this study compared two groups with one dependent variable, while ANOVA was necessary to test the effects of multiple factors simultaneously.

3.7. Ethics in Mixed Methods Research

Ethics in mixed methods research is crucial due to the complexity involved, which may present potential ethical issues (Stadnick et al., 2021). In this study, we are committed to adhering to ethical principles throughout each phase of the research, as outlined by Saheb and Saheb (2024), who emphasize the importance of respecting participants' rights and privacy while ensuring the reliability and validity of the data. Before the research commenced, we obtained informed consent from students, teachers, and the school principal through signed consent forms. These forms included detailed information about the purpose of the study, the methods used, potential risks, and participants' rights, including their right to withdraw at any time without any consequences. To ensure data confidentiality, participants' identities were protected using initials (see Table 1), and no personally identifiable information was recorded or disclosed. Additionally, regular discussions among researchers were conducted to ensure that data collection and analysis remained objective, minimizing potential biases that could influence the research outcomes. This approach aims to ensure transparency and uphold ethical standards in research.

4. Results

This study evaluates the impact of integrated PBL and flipped classroom on computational thinking skills (decomposition, pattern recognition, abstraction, algorithmic thinking) among high school students. Descriptive statistics obtained show a significant difference between the performance of the control and experimental classes in all four aspects of computational skills, as presented in Table 6.

Table 6. Descriptive statistics of computational thinking skills.

Skill	Class	N	Mean	Standard Deviation
Decomposition	Control	45	49.64	8.49
	Experiment	46	60.01	9.91
Pattern recognition	Control	45	36.22	6.17
	Experiment	46	40.74	6.52
Abstraction	Control	45	30.51	5.87
	Experiment	46	35.78	5.95
Algorithmic thinking	Control	45	34.30	6.44
	Experiment	46	38.78	5.66

This table shows that the average decomposition skill score for the control class is 49.64 with a standard deviation of 8.49, while the experimental class shows an improvement with an average score of 60.01 and a standard deviation of 9.91. Interview results support this finding, with many respondents explaining how the projects helped them break down complex problems into smaller, manageable parts. Albert mentioned, "The projects in class helped me see how the theory we learned applies to real-life situations". Patricia added, "in the transformation geometry project, I had to break a big problem into smaller, more manageable steps".

For pattern recognition skills, the control class recorded an average of 36.22 with a standard deviation of 6.17, while the experimental class had an average of 40.74 with a standard deviation of 6.52, indicating the effectiveness of this learning method in helping students better recognize patterns. Interview results support this finding, with Albert explaining, "I now understand how certain patterns in geometry transformations can be applied to other problems". Patricia added, "When I break down geometry problems, I can see patterns in the shape changes and how the steps relate to each other".

Next, the average score for abstraction skills in the control class is 30.51 with a standard deviation of 5.87, while the experimental class shows an improvement with an average of 35.78 and a standard deviation of 5.95. Interviews indicate that students were more capable of filtering out important information and focusing on the key aspects of the problems. Collins said, "With the flipped classroom method, I can learn to filter important information before the project starts, so I can focus on relevant parts". Patricia stated, "The group projects taught me to focus on the essential elements of the problem and ignore irrelevant details".

Finally, for algorithmic thinking skills, the control class had an average of 34.30 with a standard deviation of 6.44, while the experimental class showed a higher average of 38.78 with a standard deviation of 5.66. The flipped classroom process helped prepare students to think more systematically when solving problems. Albert revealed, "the flipped classroom helped me create systematic steps to solve math problems". Donna added, "When I had to create a simple algorithm for the project, I learned to organize the solution steps more neatly".

Integrated PBL and flipped classrooms proved to be effective in improving computational thinking skills (decomposition, pattern recognition, abstraction, algorithmic thinking) in students. PBL integrated with a flipped classroom helps develop computational thinking skills through structured, interactive, and PBL experiences. The combination of online videos, class discussions, and project activities enables students to directly practice concepts, effectively improving decomposition, pattern recognition, abstraction, and algorithmic thinking skills. To test the research hypothesis comprehensively, statistical analysis involved normality tests (Table 7), homogeneity tests, F-tests, and *t*-tests.

Table 7. Results of homogeneity test.

Skill	Levene Statistic	Significance
Decomposition	0.31	0.59
Pattern recognition	0.08	0.79
Abstraction	1.30	0.26
Algorithmic thinking	2.60	0.12

Levene's test showed that all variables had homogeneous variances ($p > 0.05$). The homogeneity of variance between the control and experimental groups ensures that the comparison of results can be made fairly, without distortion from differences in data distribution. This uniformity provides confidence in the results of the *t*-test and F-test, as shown in Table 8, which are used to measure the impact of the treatment, namely the integrated PBL and flipped classroom method, more accurately and convincingly.

Table 8. Results of F-test.

Model	Sum of Squares	Mean Square	F	Significance
Regression	2184.437	546.109	10.88	0.000
Residual	1053.425	50.163		
Total	3237.862			

The calculated F value of 10.88 with $p = 0.000$ indicates a highly significant difference between the control and experimental groups. This result shows that integrated PBL and flipped classrooms make a significant contribution to influencing students' computational thinking skills. Based on interviews with 10 students, integrated PBL and flipped classrooms facilitate self-directed learning, supported by video materials, which help students prepare better before collaborating on the transformation geometry project. A student expressed, "Patricia mentioned, 'I feel more prepared with the material before the class meeting because I already have an idea of what will be discussed. However, I sometimes need more explanation about some parts of the material I don't understand from the video.'" and "The videos provided are clear and to the point, but sometimes some materials are too long, requiring more time to understand them" (Creswell's expression).

The projects not only enhance computational thinking skills but also utilize simulations and digital tools to deepen the understanding of more complex concepts. Additionally, motivation and self-confidence play crucial roles in motivating students to feel more confident in solving complex problems, which impacts their computational thinking skills. One student shared, "I feel more confident, Sir. I can now more easily analyze and solve complex problems, especially in math and geometry, where I need to think critically and analytically" (Katy's expression). "Alhamdulillah (an expression of gratitude in Arabic), I am confident, Sir, because this method trains me to always think before acting. I've become more skilled at analyzing problems" (Albert's expression).

The figure illustrates how the integration of PBL with the flipped classroom contributes to the development of students' computational thinking skills. This approach not only fosters collaboration in projects but also facilitates self-directed learning through video materials, enabling students to grasp concepts before face-to-face sessions. Additionally, self-directed learning is reinforced by simulations and digital tools, which assist students in deepening their conceptual understanding and enhancing their problem-solving skills systematically. Beyond improving conceptual understanding, this approach also plays a crucial role in cultivating students' motivation and self-confidence. Active engagement in problem-based projects allows students to feel more prepared and confident in analyzing and solving complex challenges. Thus, the integration of PBL and the flipped classroom not only supports computational thinking skills but also fosters a more independent, interactive, and technology-driven learning environment.

Table 9 presents the results of the *t*-test for the regression model, which evaluates the contribution of each independent variable decomposition, pattern recognition, abstraction, and algorithmic thinking toward the dependent variable. The constant coefficient of 55.92 with a t-value of 5.50 and significance of 0.000 shows that when all independent variables are zero, the dependent variable still holds a significant value. This *p*-value < 0.05 confirms that the constant in the model has a relevant contribution.

Table 9. Results of *t*-test.

Model	Unstandardized Coefficients	Standardized Coefficients	t	Significance
(Constant)	55.92		5.50	0.000
Decomposition	1.92	1.67	5.58	0.000
Pattern recognition	−1.99	−1.16	−3.76	0.001
Abstraction	1.03	0.54	2.15	0.044
Algorithmic thinking	−1.45	−0.72	−3.59	0.002

The decomposition variable has an unstandardized coefficient of 1.92 and a standardized coefficient of 1.67, with a t-value of 5.58 and significance of 0.000, indicating that decomposition has a strong and significant positive effect on the dependent variable. Each unit increase in decomposition will increase the dependent variable by 1.92 units. In contrast, pattern recognition has an unstandardized coefficient of −1.99 and a standardized coefficient of −1.16, with a t-value of −3.76 and significance of 0.001. This result indicates that pattern recognition has a significant negative effect, reducing the dependent variable by 1.99 units for every one-unit increase in this variable.

Meanwhile, abstraction has an unstandardized coefficient of 1.03 and a standardized coefficient of 0.54, with a t-value of 2.15 and significance of 0.044, indicating a positive and significant contribution, although the level of significance is lower than the other variables. Each unit increase in abstraction will increase the dependent variable by 1.03 units. Finally, algorithmic thinking has an unstandardized coefficient of −1.45 and a standardized coefficient of −0.72, with a t-value of −3.59 and significance of 0.002, which indicates a significant negative effect on the dependent variable. Each unit increase in algorithmic thinking will decrease the dependent variable by 1.45 units.

5. Discussion

The results of this study indicate that the implementation of project-based learning (PBL) integrated with flipped classrooms significantly impacts the enhancement of students' computational thinking skills. This method has proven effective in facilitating active student engagement, enriching the learning process, and deepening the understanding of complex concepts. Specifically, this study tested four hypotheses related to computational thinking skills: decomposition, pattern recognition, abstraction, and algorithmic thinking. The findings confirmed that the experimental group outperformed the control group in all four dimensions, highlighting the efficacy of the integrated flipped PBL classroom approach in fostering computational thinking development.

The most striking improvement was observed in decomposition skills. The significantly higher average scores of students in the experimental group compared to the control group underscore the effectiveness of integrated PBL with flipped classroom in helping students break down complex problems into simpler components. Shin et al. (2021) support this finding, as PBL provides a complex structure for students to focus on key elements of a problem. This approach encourages students to analyze and understand each component in an organized manner, thereby improving their ability to solve computational problems more efficiently. Additionally, Buitrago-Florez et al. (2019) emphasized that the integrated project strategy strengthens students' analytical skills, facilitating in-depth understanding and application of concepts in various situations. These results suggest that integrating project-based approaches with flipped learning not only enhances computational thinking but also fosters critical problem-solving abilities applicable across different disciplines.

Pattern recognition skills also showed significant improvement. The integration of PBL and flipped classroom created a learning environment that nurtures students' ability to recognize patterns in data and identify relevant patterns. This aligns with the findings of Yasin and Nusantara (2023), who identified pattern recognition as a key aspect in the development of computational thinking. Abdullah et al. (2019) further emphasized that the use of integrated gaming technology accelerates the pattern recognition process, making students more responsive and accurate in identifying patterns. Chan et al. (2021) also support this finding, as computational thinking activities integrated with digital tools deepen students' understanding of patterns and mathematical relationships, enhancing the positive impact of integrated PBL and flipped classrooms (Saad & Zainudin, 2024; Xing & Zeng, 2024). In a broader context, these findings indicate that incorporating structured pattern recognition activities into computational learning can lead to better problem-solving capabilities in real-world applications, such as data analysis and artificial intelligence development.

In the area of abstraction, students taught with integrated PBL and flipped classrooms demonstrated a better ability to simplify information and focus on essential elements. This result is in line with the findings of Nurbekova et al. (2020), who emphasized that visualization technology helps students manage and simplify complex information by disregarding irrelevant details. The integrated project approach encourages students to effectively practice abstraction through active performing activities, which enhances their ability to devise efficient and relevant solutions. This finding is also supported by Indriati et al. (2024), who found that authentic tasks in PBL strengthen critical thinking skills, prompting students to separate essential information from secondary data (Zhang et al., 2024). Given that abstraction is a crucial skill in computational problem-solving, the observed improvements suggest that educators should integrate more visualization tools and real-world problem scenarios to strengthen students' ability to generalize and apply knowledge beyond the classroom.

However, algorithmic thinking, while showing improvement, still presents challenges. Some students struggled with constructing systematic algorithmic solutions, indicating the need for additional strategies. Ergin and Arıkan (2023) demonstrated that while PBL enhances algorithmic skills, students often require additional scaffolding before mastering text-based programming. This aligns with Voon et al. (2022), who stated that the use of constructivist argumentation can assist students in designing more effective algorithms through discussion and reflection. These findings imply that while PBL and flipped classroom methods are beneficial, additional instructional support such as guided practice in algorithm design and step-by-step debugging exercises is necessary to optimize students' algorithmic thinking skills.

This research underscores that integrated PBL with a flipped classroom is an effective approach in computational education, where students develop essential skills to tackle real-world challenges. Wang (2024) highlighted that computational thinking is key to innovation in various fields, and this study demonstrates that integrated PBL with a flipped classroom can successfully integrate these skills into the curriculum in a productive manner. A meta-analysis by Zhang et al. (2024) further reinforces this finding, stating that PBL significantly enhances students' creativity, collaboration, and critical thinking. Online PBL has been proven to increase students' metacognitive awareness (Kalemkuş & Bulut-Özek, 2022; Shekh-Abed, 2024; Tu et al., 2025). From a practical standpoint, these results suggest that implementing a structured and well-supported flipped PBL classroom model can be beneficial not only for computational education but also for broader STEM-based learning environments. Future research should explore the long-term impact of this approach on students' ability to transfer computational thinking skills to real-world technological and professional settings.

6. Conclusions

This study demonstrates that the implementation of project-based learning (PBL) integrated with a flipped classroom significantly enhances students' computational thinking skills. The findings confirm that students in the experimental group outperformed those in the control group across all four dimensions: decomposition, pattern recognition, abstraction, and algorithmic thinking. Specifically, students using this approach were able to break down complex problems into simpler parts (decomposition), recognize patterns more effectively (pattern recognition), and simplify information by focusing on key elements (abstraction). These improvements highlight the effectiveness of integrated PBL in fostering problem-solving skills and optimizing class time for deeper conceptual engagement.

While improvements were also observed in algorithmic thinking, challenges remain. Some students experienced difficulty in constructing systematic and efficient algorithmic solutions, indicating the need for additional scaffolding and structured guidance. This suggests that supplementary instructional strategies, such as guided coding exercises or adaptive learning tools, may be necessary to reinforce algorithmic reasoning.

The results of this study provide valuable insights for educators, curriculum developers, and policymakers. The integration of PBL with flipped classrooms can serve as an effective pedagogical model to promote computational thinking in mathematics and computer science education. Schools and institutions should consider adopting structured PBL frameworks with digital resources to maximize student engagement and learning outcomes. Additionally, teacher training programs should incorporate strategies for implementing flipped PBL effectively, particularly in subjects requiring higher-order cognitive skills.

This study has some limitations, namely that the sample was limited to a single school, which restricts the generalization of the results. Differences in cultural contexts, classroom environments, and technological accessibility may influence the effectiveness of this method. Additionally, the quasi-experimental design used has limitations in controlling external variables that may impact the results.

Future research should explore larger-scale studies across multiple schools to assess the scalability and adaptability of the integrated PBL approach. Longitudinal studies are also needed to examine the long-term effects of computational thinking development. Furthermore, qualitative research using grounded theory could provide deeper insights into students' conceptual understanding of transformational geometry. Additionally, integrating adaptive learning technologies could support students struggling with algorithmic thinking, making the learning process more personalized and effective. These findings underscore the transformative potential of PBL and flipped classrooms in preparing students for computational problem-solving in the digital era.

Author Contributions: Conceptualization, M.F. and A.S.; Methodology, M.F., C.S., W.W., N.Y., M.P.S.J. and S.B.; Software, M.F. and S.B.; Validation, A.S. and C.S.; Formal analysis, M.F., W.W. and I.S.; Investigation, N.Y., M.P.S.J., J.G.P., A.A. and I.S.; Resources, N.Y., M.P.S.J., J.G.P., A.A. and I.S.; Data curation, N.Y., J.G.P. and A.A.; Writing—original draft, M.F.; Writing—review & editing, M.F. and A.S.; Visualization, M.F. and S.B.; Supervision, A.S., C.S. and W.W.; Project administration, N.Y., M.P.S.J., J.G.P., A.A. and I.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by BPPT Kemendikbudristek and LPDP (grant number 01627/BPPT/BPI.06/9/2023).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Dean of the Faculty of Social Sciences, Universitas Negeri Yogyakarta (protocol code B/1711/UN34.14/PT.01.04/2024; date of approval: 30 April 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The research data can be accessed upon request and with approval from the research team. For inquiries regarding the data, please contact the principal investigator, Muh. Fitrah, via email at muhfitrah.2023@student.uny.ac.id or through LinkedIn at Muh. Fitrah.

Conflicts of Interest: The authors declare no conflict of interest.

References

Abdullah, A. H., Othman, M. A., Ismail, N., Rahman, S. N. S. A., Mokhtar, M., & Zaid, N. M. (2019, December 10–13). *Development of mobile application for the concept of pattern recognition in computational thinking for mathematics subject*. TALE 2019—2019 IEEE International Conference on Engineering, Technology and Education, Yogyakarta, Indonesia. [CrossRef]

AlAli, R. (2024). Enhancing 21st century skills through integrated STEM education using project-oriented problem-based learning. *Geo Journal of Tourism and Geosites*, *53*(2), 421–430. [CrossRef]

Alonso-García, S., Fuentes, A.-V. R., Navas-Parejo, M. R., & Victoria-Maldonado, J.-J. (2024). Enhancing computational thinking in early childhood education with educational robotics: A meta-analysis. *Heliyon*, *10*(13), e33249. [CrossRef] [PubMed]

Awi, A., Naufal, M. A., Sutamrin, S., & Huda, M. (2024). Enhancing geometry achievement in pre-service mathematics teachers: The Impact of a scaffolded flipped classroom using a learning management system. *Journal of Ecohumanism*, *3*(6), 637–645. [CrossRef]

Bergmann, J., & Sams, A. (2012). Before you flip, consider this. *Phi Delta Kappan*, *94*(2), 25. [CrossRef]

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *26*(3–4), 369–398. [CrossRef]

Bolivar, R., Triviño Jaimes, N. R., & Gonzalez, E. A. (2023). Implementation and benefits of hybrid methodology: Flipped classroom and project-based learning in mechanical engineering courses. *International Journal of Mechanical Engineering Education*, *53*(1), 102–124. [CrossRef]

Buitrago-Florez, F., Danies, G., Restrepo, S., & Hernandez, C. (2019). Boosting 21st century competences through computational thinking and student centered strategies. In R. M. Lima, V. Villas-Boas, L. Bettaieb, & K. Akrout (Eds.), *International symposium on project approaches in engineering education* (Vol. 9, pp. 48–55). University of Minho. Available online: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85074940602&partnerID=40&md5=a4b4579100d67026f1f9a85e993fc03b (accessed on 14 September 2024).

Çakiroğlu, Ü., & Erdemir, T. (2018). Online project based learning via cloud computing: Exploring roles of instructor and students. *Interactive Learning Environments*, *27*(4), 547–566. [CrossRef]

Chan, S.-W., Looi, C.-K., Ho, W. K., Huang, W., Seow, P., & Wu, L. (2021). Learning number patterns through computational thinking activities: A Rasch model analysis. *Heliyon*, *7*(9), e07922. [CrossRef]

Charbonneau-Gowdy, P., Cubric, M., Pechenkina, K., Dyer, R., Pyper, A., Söbke, H., & Spangenberger, P. (2023). EJEL editorial 2023: Trends and research gaps in e-learning. *Electronic Journal of E-Learning*, *21*(3), 248–257. Available online: http://www.ejel.org/ (accessed on 15 September 2024).

Clark, K. R. (2015). The effects of the flipped model of instruction on student engagement and performance in the secondary mathematics classroom. *Journal of Educators Online*, *12*(1), 91–115. Available online: https://files.eric.ed.gov/fulltext/EJ1051042.pdf (accessed on 7 March 2025).

Craig, T. T., & Marshall, J. (2019). Effect of project-based learning on high school students' state-mandated, standardized math and science exam performance. *Journal of Research in Science Teaching*, *56*(10), 1461–1488. [CrossRef]

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods aapproaches*. Sage Publications, Inc.

Cubric, M., & Tripathi, V. (2009). A semantic web framework for generating collaborative e-learning environments. *International Journal of Emerging Technologies in Learning*, *4*(3), 4–7. [CrossRef]

del Olmo-Muñoz, J., Bueno-Baquero, A., Cózar-Gutiérrez, R., & González-Calero, J. A. (2023). Exploring gamification approaches for enhancing computational thinking in young learners. *Education Sciences*, *13*(5), 487. [CrossRef]

Deng, R., Feng, S., & Shen, S. (2023). Improving the effectiveness of video-based flipped classrooms with question-embedding. *Education and Information Technologies*, *29*(10), 12677–12702. [CrossRef]

Dinh, C. T., & Phuong, H. (2025). Teaching self-regulated learning strategies on efl students in moocs: A case study in Vietnam. *Turkish Online Journal of Distance Education*, *26*(1), 101–121. [CrossRef]

Dong, X., Zhang, X., & Li, X. (2024, July 29–August 1). *Project-based flipped classroom model focusing on outcome communication and evaluation*. 2024 International Symposium on Educational Technology (ISET) (pp. 305–309), Macau, Macao. [CrossRef]

Durak, H. Y., & Saritepeci, M. (2018). Analysis of the relation between computational thinking skills and various variables with the structural equation model. *Computers & Education*, *116*, 191–202. [CrossRef]

Egara, F. O., & Mosimege, M. (2023). Effect of flipped classroom learning approach on mathematics achievement and interest among secondary school students. *Education and Information Technologies*, *29*(7), 8131–8150. [CrossRef]

Ergin, H., & Arıkan, Y. D. (2023). The effect of project based learning approach on computational thinking skills and programming self-efficacy beliefs. *AJIT-e: Academic Journal of Information Technology*, *14*(55), 320–334. [CrossRef]

Ersozlu, Z., Swartz, M., & Skourdoumbis, A. (2023). Developing computational thinking through mathematics: An evaluative scientific mapping. *Education Sciences*, *13*(4), 422. [CrossRef]

Erstad, O. (2002). Norwegian students using digital artifacts in project-based learning. *Journal of Computer Assisted Learning*, *18*(4), 427–437. [CrossRef]

Fernández-Martín, F.-D., Romero-Rodríguez, J.-M., Gómez-García, G., & Ramos Navas-Parejo, M. (2020). Impact of the flipped classroom method in the mathematical area: A systematic review. *Mathematics*, *8*(12), 2162. [CrossRef]

Fredriksen, H., Rebenda, J., Rensaa, R. J., & Pettersen, P. (2024). Inquiry-based linear algebra teaching and learning in a flipped classroom framework: A case study. *PRIMUS*, 1–21. [CrossRef]

Gibson, I. S., O'Reilly, C., & Hughes, M. (2002). Integration of ICT within a project-based learning environment. *European Journal of Engineering Education*, *27*(1), 21–30. [CrossRef]

Gondal, S. A., Khan, A. Q., Cheema, E. U., & Dehele, I. S. (2024). Impact of the flipped classroom on students' academic performance and satisfaction in Pharmacy education: A quasi-experimental study. *Cogent Education*, *11*(1), 2378246. [CrossRef]

Gong, J., Cai, S., & Cheng, M. (2023). Exploring the effectiveness of flipped classroom on STEM student achievement: A meta-analysis. *Technology, Knowledge and Learning*, *29*(2), 1129–1150. [CrossRef]

Holmes, V.-L., & Hwang, Y. (2016). Exploring the effects of project-based learning in secondary mathematics education. *The Journal of Educational Research*, *109*(5), 449–463. [CrossRef]

Hossein-Mohand, H., Trujillo-Torres, J.-M., Gómez-García, M., Hossein-Mohand, H., & Campos-Soto, A. (2021). Analysis of the use and integration of the flipped learning model, project-based learning, and gamification methodologies by secondary school mathematics teachers. *Sustainability*, *13*(5), 2606. [CrossRef]

Indriati, L., Mai, N., & Tan, H. Y.-J. (2024). Enhancing authentic assessment in large-class design education through authentic project-based learning. *International Journal of Learning, Teaching and Educational Research*, *23*(9), 432–452. [CrossRef]

Isabel Santos, A., & Serpa, S. (2020). Flipped classroom for an active learning. *Journal of Education and E-Learning Research*, *7*(2), 167–173. [CrossRef]

Kalemkuş, F., & Bulut-Özek, M. (2022). The effect of online project-based learning on metacognitive awareness of middle school students. *Interactive Learning Environments*, *32*(4), 1533–1551. [CrossRef]

Kim, D., & Lee, S. (2002). Designing collaborative reflection supporting tools in e-project-based learning environments. *Journal of Interactive Learning Research*, *13*(4), 375–392. Available online: https://www.learntechlib.org/primary/p/9530/ (accessed on 7 March 2025).

Kong, S. C. (2014). Developing information literacy and critical thinking skills through domain knowledge learning in digital classrooms: An experience of practicing flipped classroom strategy. *Computers & Education*, *78*, 160–173. [CrossRef]

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1994). A collaborative model for helping middle grade science teachers learn project-based instruction. *The Elementary School Journal*, *94*(5), 483–497. [CrossRef]

Kramer, B. S., Walker, A. E., & Brill, J. M. (2007). The underutilization of information and communication technology-assisted collaborative project-based learning among international educators: A Delphi study. *Educational Technology Research and Development*, *55*(5), 527–543. [CrossRef]

Li, M.-M., & Tu, C.-C. (2024). Developing a project-based learning course model combined with the think–pair–share strategy to enhance creative thinking skills in education students. *Education Sciences*, *14*(3), 233. [CrossRef]

Liu, L., Hew, K. F., & Du, J. (2024). Design principles for supporting self-regulated learning in flipped classrooms: A systematic review. *International Journal of Educational Research*, *124*, 102319. [CrossRef]

Maros, M., Korenkova, M., Fila, M., Levicky, M., & Schoberova, M. (2021). Project-based learning and its effectiveness: Evidence from Slovakia. *Interactive Learning Environments*, *31*(7), 4147–4155. [CrossRef]

Meyer, D. K., Turner, J. C., & Spencer, C. A. (1997). Challenge in a mathematics classroom: Students' motivation and strategies in project-based learning. *The Elementary School Journal*, *97*(5), 501–521. [CrossRef]

Mohamed, H., Saidalvi, A., & Tashiron, N. A. (2019). Project based learning in flipped classroom based on student's cognitive style. *International Journal of Recent Technology and Engineering*, *7*(6S3), 696–700.

Moss, D. M. (2000). Bringing together technology and students: Examining the use of technology in a project-based class. *Journal of Educational Computing Research*, *22*(2), 155–169. [CrossRef]

My Nguyen, H. T., Chau Nguyen, G. T., Hong Thai, L. T., Truong, D. T., & Nguyen, B. N. (2024). Teaching Mathematics through project-based learning in K-12 Schools: A systematic review of current practices, barriers, and future developments. *TEM Journal*, *13*, 2054–2065. [CrossRef]

Nayak, A., Satpathy, I., & Jain, V. (2024). The project-based learning approach (PBL): Enthralling students through Project-Based Learning approach (PBL) in Education 5.0. In *Preconceptions of Policies, Strategies, and Challenges in Education 5.0* (pp. 158–174). IGI Global. [CrossRef]

Ndiung, S., & Menggo, S. (2024). Project-based learning in fostering creative thinking and mathematical problem-solving skills: Evidence from primary education in Indonesia. *International Journal of Learning, Teaching and Educational Research*, *23*(8), 289–308. [CrossRef]

Nurbekova, Z., Grinshkun, V., Aimicheva, G., Nurbekov, B., & Tuenbaeva, K. (2020). Project-based learning approach for teaching mobile application development using visualization technology. *International Journal of Emerging Technologies in Learning (IJET)*, *15*(08), 130. [CrossRef]

Patterson, B., McBride, C. R., & Gieger, J. L. (2018). Flipped active learning in your mathematics classroom without videos. *PRIMUS*, *28*(8), 742–753. [CrossRef]

Pokhrel, M., Sharma, L., Sharma, T., Prasad, M., & Poudel, L. G. C. (2024). Enhancing mathematics learning through self-directed pedagogy: Strategies and evaluation techniques for effective student engagement. *Journal of Computational Analysis and Applications*, *33*(8), 841–854. Available online: https://eudoxuspress.com/index.php/pub/article/view/1471 (accessed on 22 October 2024).

Rehman, N., Huang, X., Mahmood, A., AlGerafi, M. A. M., & Javed, S. (2024). Project-based learning as a catalyst for 21st-Century skills and student engagement in the math classroom. *Heliyon*, *10*(23), e39988. [CrossRef]

Remijan, K. W. (2017). Project-based learning and design-focused projects to motivate secondary mathematics students. *Interdisciplinary Journal of Problem-Based Learning*, *11*(1), 1–15. [CrossRef]

Rijken, P. E., & Fraser, B. J. (2023). Effectiveness of project-based mathematics in first-year high school in terms of learning environment and student outcomes. *Learning Environments Research*, *27*(2), 241–263. [CrossRef]

Rodríguez-Martínez, J. A., González-Calero, J. A., & Sáez-López, J. M. (2019). Computational thinking and mathematics using Scratch: An experiment with sixth-grade students. *Interactive Learning Environments*, *28*(3), 316–327. [CrossRef]

Saad, A., & Zainudin, S. (2024). A review of teaching and learning approach in implementing Project-Based Learning (PBL) with Computational Thinking (CT). *Interactive Learning Environments*, *32*(10), 7622–7646. [CrossRef]

Saheb, T., & Saheb, T. (2024). Mapping ethical artificial intelligence policy landscape: A mixed method analysis. *Science and Engineering Ethics*, *30*(2), 9. [CrossRef]

See, S., & Conry, J. M. (2014). Flip My Class! A faculty development demonstration of a flipped-classroom. *Currents in Pharmacy Teaching and Learning*, *6*(4), 585–588. [CrossRef]

Shekh-Abed, A. (2024). Metacognitive self-knowledge and cognitive skills in project-based learning of high school electronics students. *European Journal of Engineering Education*, *50*(1), 214–229. [CrossRef]

Shen, Y. (2024). Examining the efficacies of instructor-designed instructional videos in flipped classrooms on student engagement and learning outcomes: An empirical study. *Journal of Computer Assisted Learning*, *40*(4), 1791–1805. [CrossRef]

Shin, N., Bowers, J., Krajcik, J., & Damelin, D. (2021). Promoting computational thinking through project-based learning. *Disciplinary and Interdisciplinary Science Education Research*, *3*(1), 7. [CrossRef] [PubMed]

Singha, R., & Singha, S. (2024). Application of experiential, inquiry-based, problem-based, and project-based learning in sustainable education. In *Teaching and learning for a sustainable future: Innovative strategies and best practices* (pp. 109–128). IGI Global. [CrossRef]

Soboleva, E. V., Kirillova, E. P., Lomakin, D. E., & Gribkov, D. N. (2021). Formation of computational thinking skills in the development of computer games for educational purposes. *Perspektivy Nauki i Obrazovania*, *49*(1), 464–477. [CrossRef]

Stadnick, N. A., Poth, C. N., Guetterman, T. C., & Gallo, J. J. (2021). Advancing discussion of ethics in mixed methods health services research. *BMC Health Services Research*, *21*(1), 577. [CrossRef]

Sung, W., Ahn, J., & Black, J. B. (2017). Introducing computational thinking to young learners: Practicing computational perspectives through embodiment in mathematics education. *Technology, Knowledge and Learning*, *22*(3), 443–463. [CrossRef]

Sung, W., & Black, J. B. (2020). Factors to consider when designing effective learning: Infusing computational thinking in mathematics to support thinking-doing. *Journal of Research on Technology in Education*, *53*(4), 404–426. [CrossRef]

Tekin, O., & Sarıkaya, E. E. (2020). Flipped classroom model in high school mathematics. *Bartın University Journal of Faculty of Education*, *9*(2), 301–314.

Tu, F., Wu, L., Kinshuk, Ding, J., & Chen, H. (2025). Exploring the influence of regulated learning processes on learners' prestige in project-based learning. *Education and Information Technologies*, *30*, 2299–2329. [CrossRef]

Tucker, B. (2012). The flipped classroom. *Education Next*, *12*(1), 82–83. Available online: https://www.educationnext.org/wp-content/uploads/2023/04/ednext_XII_1_what_next.pdf (accessed on 7 March 2025).

Voon, X. P., Wong, S. L., Wong, L.-H., Khambari, M. N. M., & Syed-Abdullah, S. I. S. (2022). Developing computational thinking competencies through constructivist argumentation learning: A problem-solving perspective. *International Journal of Information and Education Technology*, *12*(6), 529–539. [CrossRef]

Wang, J. (2024). Research on the flipped classroom + learning community approach and its effectiveness evaluation—Taking college german teaching as a case study. *Sustainability*, *16*(17), 7719. [CrossRef]

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2015). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147. [CrossRef]

Xing, D., & Zeng, Y. (2024). Exploring the effects of secondary school student's information and communication technology literacy on computational thinking skills in the smart classroom environment. *Education and Information Technologies*. [CrossRef]

Yasin, M., & Nusantara, T. (2023). Characteristics of pattern recognition to solve mathematics problems in computational thinking. In *AIP conference proceedings* (vol. 2569, p. 40009). AIP Publishing. [CrossRef]

Zarouk, M. Y., Olivera, E., Peres, P., & Khaldi, M. (2020). The impact of flipped project-based learning on self-regulation in higher education. *International Journal of Emerging Technologies in Learning (IJET)*, *15*(17), 127. [CrossRef]

Zhang, W., Guan, Y., & Hu, Z. (2024). The efficacy of project-based learning in enhancing computational thinking among students: A meta-analysis of 31 experiments and quasi-experiments. *Education and Information Technologies*, *29*(11), 14513–14545. [CrossRef]