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Impact of problem-based learning on critical thinking: An exploration with middle school students

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Abstract

Critical thinking is a fundamental skill in 21st-century education, enabling students to analyze information, evaluate evidence, and make informed decisions. Traditional teaching methods often fail to effectively foster critical thinking. Problem-Based Learning (PBL) has been identified as a promising pedagogical approach for enhancing students' critical thinking by engaging them in real-world problem-solving activities. However, empirical research on its effectiveness in middle school students remains limited. This study examined the impact of PBL on the development of critical thinking skills among middle school students. Specifically, it investigates (1) how PBL influences critical thinking, (2) the differences in critical thinking skills between PBL and traditional instruction, and (3) the validity of the Watson-Glaser Critical Thinking Appraisal (WGCTA) in assessing middle school students in a PBL context. A quasi-experimental study was conducted with 240 ninth-grade students divided into experimental (PBL-based) and control (traditional instruction) groups. Critical thinking skills, including inference, assumption recognition, deduction, interpretation, and argument evaluation, were measured using WGCTA. The data analysis involved Confirmatory Factor Analysis (CFA), Pearson correlation, and radar chart visualization. Students in the PBL group significantly outperformed those in the control group on all critical thinking dimensions. The most significant gains were observed in the inference, deduction, and evaluation of arguments. The CFA results confirmed the reliability and validity of the WGCTA for middle school students (CFI = 0.994, RMSEA = 0.020). This study highlights PBL as an effective method for enhancing critical thinking among middle school students. These findings support the integration of structured PBL strategies into curriculum design to improve students' analytical and problem-solving skills.

Keywords: Confirmatory factor analysis, Critical thinking, Middle school education, Problem-based learning, WGCTA.

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1. Introduction and Theoretical Basis

In the context of modern education, critical thinking has become one of the core skills that help students succeed in their studies and lives [1, 2]. This skill allows students to analyze information, evaluate evidence, and make scientifically based decisions. Critical thinking is considered one of the most important goals of the 21st century curriculum [2]. Practicing critical thinking helps students develop the ability to ask questions, analyze information, evaluate evidence, and make decisions appropriate to the practical context [3]. In education and other fields, developing critical thinking helps students improve their problem-solving and decision-making abilities [2]. According to Facione [1] critical thinking includes skills such as interpretation, analysis, inference, evaluation, and self-regulation. However, many studies have shown that traditional teaching methods are not effective in developing critical thinking in students, especially in middle schools [3, 4].

Problem-based learning (PBL) has been proposed as an effective teaching method for enhancing critical thinking by placing students in real-world situations and encouraging them to seek solutions through research and debate [5, 6]. Although much research has been conducted on PBL in higher education, there is a lack of empirical research examining the impact of this method on secondary school students [7, 8].

Additionally, the assessment of critical thinking remains a major challenge in educational research. Watson-Glaser Critical Thinking Appraisal (WGCTA) has been widely used to measure critical thinking in many fields. However, few studies have applied this tool to middle school students in the PBL context [9].

This study was conducted to evaluate the impact of PBL on the development of critical thinking among secondary school students using the WGCTA test. Differences in critical thinking between students learning through PBL and students learning through traditional methods. Determine the suitability of the WGCTA for measuring secondary school students' critical thinking in the context of PBL.

1.1. Research Questions

RQ1: How does PBL affect the development of critical thinking among middle school students?

RQ2: What are the differences in critical thinking between students who learn through PBL and those who learn using traditional methods?

RQ3: Is WGCTA suitable for measuring critical thinking among middle school students in the context of PBL?

1.2. Concept of Critical Thinking

Critical thinking is a core cognitive skill that enables individuals to analyze, evaluate, and reason logically and systematically. Paul and Elder [10] emphasize that critical thinking is not just a skill, but also a set of thinking habits that help individuals make decisions based on evidence and sound reasoning. According to Facione [1] critical thinking includes the following elements: interpretation, analysis, inference, evaluation, and self-regulation.

Interpretation is the ability to understand and present information meaningfully. In the context of secondary education, students must be able to interpret scientific texts, statistics, and complex arguments as a part of their learning. For example, when learning about climate change, students may be asked to interpret global temperature data over time to make judgments regarding climate trends [3]. Developing interpretation skills helps students gain a deeper understanding of the content and provides a solid foundation for approaching complex problems. An analysis is the ability to break down a problem into smaller components to better understand its nature. In PBL classrooms, students are encouraged to analyze real-world situations to determine the root causes of problems. For example, in a lesson on the environment, students might analyze the impact of air pollution on human health and then propose measures to reduce pollution [5]. Analytical skills help students not only understand the problem comprehensively but also develop the ability to think systematically.

Inference refers to the ability to draw conclusions from available data or evidence. In secondary education, students are often required to make inferences when solving open-ended problems or when performing scientific experiments. For example, in physics, students may make inferences about the cause of a phenomenon based on laboratory data [6]. Developing inference skills helps students to develop strong critical thinking skills and the ability to make reasoned decisions based on facts.

Evaluation is the ability to determine the accuracy, reliability, and value of an argument or a source of information. Middle school students are often exposed to many different sources of information, especially in the digital age; therefore, it is important to develop the ability to evaluate information. A typical example is when students are asked to compare two sources of information about climate change, one from a reputable scientific organization and one from an unknown website, to evaluate which source is more reliable [10]. This skill helps students to become active learners and strong critical thinkers.

Self-regulated thinking is the ability to be aware of and adjust one's own thinking processes to ensure that one's decisions and reasoning are sound and evidence based. In a PBL environment, students are encouraged to self-evaluate and adjust their learning strategies accordingly. For example, after completing a research project, students might ask themselves, "Did I gather enough evidence to support my conclusion?" or "Is there a better approach to solving this problem?" [2]. Practicing this skill helps students to become more flexible and autonomous in their learning.

Overall, these components of critical thinking play an important role in developing secondary school students' learning and problem-solving abilities. When integrated into the PBL method, these skills not only help students acquire knowledge more effectively but also improve their ability to reason and make decisions in real-life situations

1.3. PBL in General Education

PBL is a student-centered teaching method in which learners are exposed to real-life situations or problems and are required to find a solution through exploration, research, and collaboration [11]. PBL consists of five stages: identify, research, and analyze the problem, pose a solution, implement the solution, evaluate, and pond [12, 13]. The PBL teaching process is carried out in three stages: the initial stage, PBL stage, and final stage [14].

The first stage is the formation of learning groups that can be assigned or randomly assigned to small groups. The group is then presented with a PBL problem, and students begin to analyze it to understand it Hmelo-Silver [5]. Some specific activities at this stage include; formulating learning objectives [15] identifying knowledge gaps [16] generating hypotheses Hmelo-Silver [5] identifying learning problems and concepts to be learned, asking questions to determine "what students know," "what students don't know" and "what students need to know," the teacher acts as a facilitator of student learning in the PBL cycle Hmelo-Silver [5].

The PBL phase begins with students undertaking independent self-study Schmidt [15]. Students are required to master knowledge related to the problem to be solved. Students then proceed to discuss in groups and brainstorm individually [17]. Students exchange and share their information [15, 17] with all learning problems and hypotheses to reach an acceptable solution to the problem and a consensus among the majority of group members. Teachers monitor the progress of small groups through direct observation and process assessment [18]. Direct observation includes coaching roles such as probing and questioning to activate students' critical thinking skills [17]. Teachers then provide feedback immediately after formative assessment [19] and always encourage students to maintain self-assessment [16, 19].

In the final stage, the students prepare to present and self-evaluate the results of their group discussions or project products. Students presented a portion of their proposed solutions. Teachers evaluate student solutions based on groups or individual presentations. In some cases, rubrics can be used for peer assessment combined with teacher assessment scores for groups to calculate individual student scores [20]. Other assessment methods can also be used to monitor student progress [16].

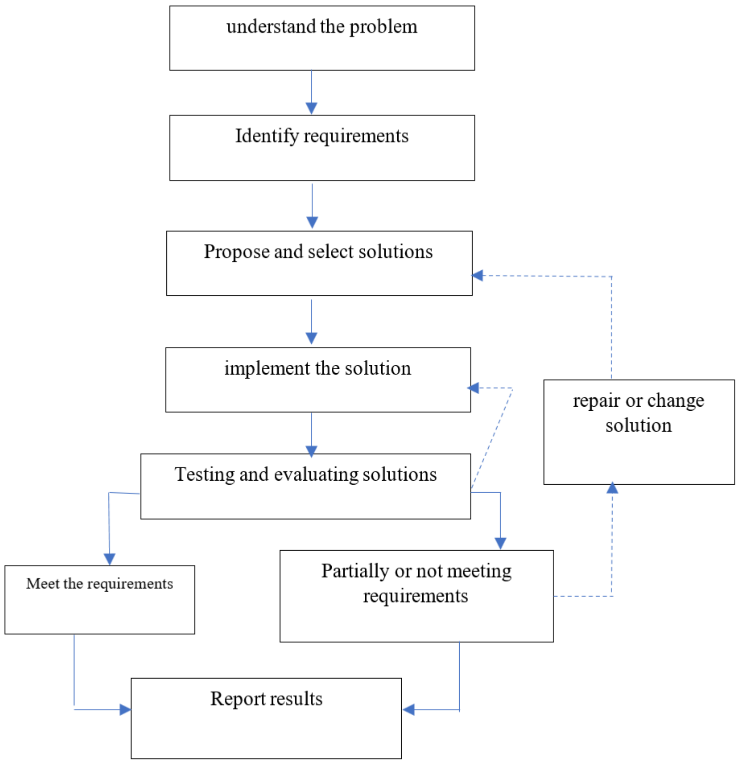

Figure 1.
PBL model in general education,
Source: Pólya [12] and Savery and Duffy [13].

PBL not only helps students develop academic knowledge but also enhances important skills, such as critical thinking, communication, teamwork, and lifelong learning [5].

Several studies have shown that PBL applied to science and engineering subjects helps students develop critical thinking skills by solving real-world problems. Phenomenon-Based Learning (PBL) has been implemented to enhance students' critical thinking and creative skills [21]. PBL applied in project-based learning has helped students develop critical thinking and problem-solving skills [5].

The process of repetition helps students understand that failure is not a negative thing, but an opportunity to learn and improve. Each failure in testing and evaluating a solution is a step toward identifying a more accurate solution [22].

1.4. The Impact of PBL on Critical Thinking in General Education

Several studies have shown that PBL has a positive impact on critical thinking among high-school students. According to a meta-analysis by Strobel and Van Barneveld [7] PBL helps students develop critical thinking skills more effectively than traditional teaching methods. The main effects of PBL on critical thinking include the following: students must analyze problems, identify causes, and predict consequences, which improve logical thinking skills [6]. Requiring students to hypothesize and test them through research helps them develop scientific reasoning skills [5]. Students must search for and evaluate sources and determine which information is reliable, thereby improving their ability to evaluate arguments [10]. During group research and reflection, students have the opportunity to adjust their perspectives when faced with new information or stronger arguments Halpern [2]. Bezanilla, et al. [4] showed that middle school students who participated in PBL showed significant improvements in critical thinking, especially in their ability to evaluate evidence and make decisions based on facts.

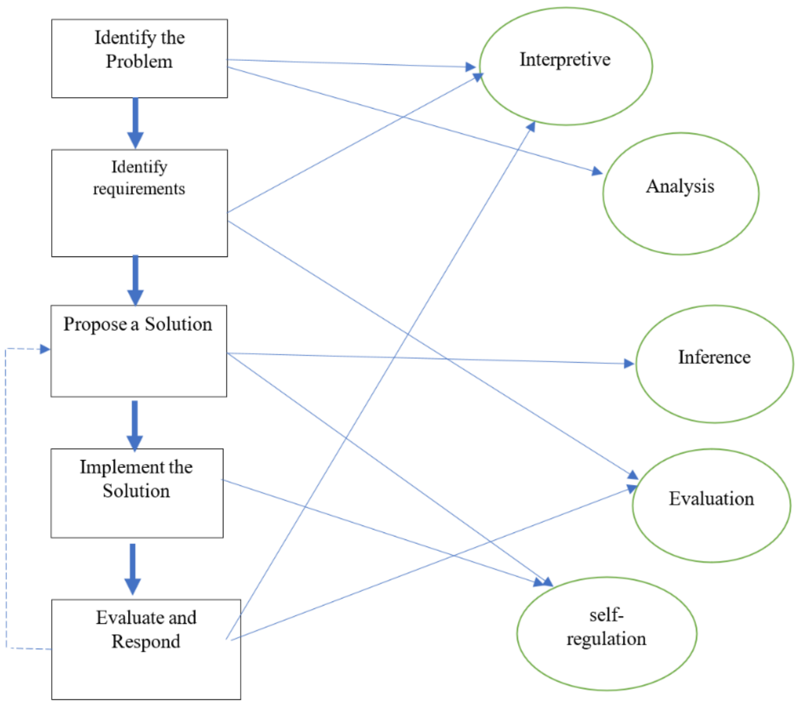

Figure 2.
Description of the Relationship between PBL and Critical Thinking.
Source: Savery and Duffy [13] and Facione [1].

Many studies have demonstrated a relationship between PBL and critical thinking (Figure 2). A study by Bezanilla, et al. [4] PBL creates a learning environment in which students must use critical thinking to evaluate potential solutions and make evidence-based decisions. This promotes the development of analytical, inferential, and evaluative skills, which are the core elements of critical thinking [1]. Another notable point is that PBL helps students develop critical thinking skills through collaboration and debate in learning groups. According to Burris and Garton [23] group learning in PBL helps students practice critical thinking, ask questions, and defend their views against opposing opinions. This not only improves thinking ability, but also trains communication and teamwork skills.

Hmelo-Silver [5] found that PBL improves critical thinking in secondary school students through questioning and analyzing real-world problems. Strobel and Van Barneveld [7] found that PBL was more effective than traditional teaching in developing critical thinking; however, this effect may vary depending on implementation and learner characteristics. A study by Abrami, et al. [3] emphasized that for PBL to be truly effective, there needs to be strong guidance from teachers to help students systematically develop critical thinking.

1.5. Research Methods and Design

This study applied an experimental method with a control group and test group. A sample of 240 secondary school students was divided into two groups: one using the traditional method, and the other using the PBL method (see Appendix 1). The two groups studied the same topic “Climate Change”

At the end of the experimental sessions, the two groups were assessed for their critical thinking skills using the same test, following the structure of the WGCTA (for sample questions, see Appendix 2).

1.6. Research Design

1.6.1. Assessment Tools

WGCTA is one of the most popular tools for assessing critical thinking. Studies have shown that the Cronbach’s alpha coefficient of the WGCTA is above 0.80, ensuring high internal consistency [9]. WGCTA can clearly distinguish between those with and without strong critical thinking, thereby providing reliable data on the level of critical thinking of students [1, 8]. This tool measures the ability to reason logically, identify assumptions, evaluate arguments, and draw conclusions based on the evidence. It can be used to assess the differences between groups of students applying PBL and traditional methods, providing objective data on the impact of PBL on critical thinking [7].

The WGCTA currently has two main versions: a long version of 80 questions in two parallel formats (Forms A and B) and a shortened version of 40 questions (Form S), which is commonly used in educational research and recruitment. In the present study, we have used a shortened version.

The structure of the WGCTA test was divided into five subsections, each assessing an important aspect of critical thinking (Table 1).

Table 1.
Structure of the WGCTA test, [9].

Skill symbol	Skills	Describe	Apply
S1	Inference	Assess the ability to draw conclusions based on available data	Students are given a text and must determine the reasonableness of the inferences made based on the information available. Objective: To assess the ability to distinguish between reasonable and unreasonable inferences
S2	Recognition of Assumptions	Tests the ability to identify underlying assumptions in arguments	Students must determine whether an argument is based on an implicit assumption. Objective: To assess students' ability to recognize implicit assumptions and evaluate the accuracy of arguments.
S3	Deduction	Determine the reasonableness of conclusions based on given premises	The test consists of a series of statements, from which students must determine what conclusions can be drawn. Objective: Tests the ability to apply logical reasoning to draw reasonable conclusions
S4	Interpretation	Evaluate the reasonableness of generalizations based on data.	Students must determine whether a given conclusion is reasonable based on the evidence provided. Objective: Assess students' understanding of the meaning and intent of arguments.
S5	Evaluation of Arguments	Distinguish between strong and weak arguments based on the level of logic and evidence	Students are given a problem or situation and a number of arguments for or against a point of view. Objective: Determine which arguments are strong and which are weak based on logic and evidence

Table 2.
Reliability of the scale scores of the experimental and control classes Item-Total Statistics.

Skill	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
S1-E	6.71	14.114	0.809	0.913
S2-E	6.48	11.628	0.811	0.910
S3-E	6.80	14.715	0.835	0.920
S4-E	6.56	12.361	0.817	0.904
S5- E	6.34	11.527	0.813	0.902
S1-C	8.14	13.846	0.842	0.909
S2-C	8.05	13.151	0.899	0.931
S3-C	8.12	13.869	0.843	0.929
S4-C	8.05	12.921	0.865	0.943
S5- C	8.03	12.821	0.853	0.918

The reliability of the skill scale by scores of the experimental class (E) and the control class (C) was assessed based on Cronbach's alpha coefficient (Table 2), showing high homogeneity and reliability in the measurement items of both groups, the experimental class, and the control class. Specifically, the overall Cronbach's alpha coefficient of the scale in the experimental class was 0.928, indicating a high level of reliability. Each item in the scale had a total item correlation coefficient greater than 0.8, proving that these items had high homogeneity. If any item is removed, Cronbach's alpha coefficient will decrease or not change significantly, proving that these items are necessary and suitable for the scale.

Similarly, the scale in the control class achieved a high overall Cronbach's alpha coefficient of 0.902. The item-total correlation coefficients of each item were all above 0.89, confirming that the items in the scale were closely linked and reflected the measured aspects. Removing any item did not improve the overall Cronbach's alpha coefficient, demonstrating the reasonableness and necessity of items in the scale structure.

1.7. Analysis Of Learning Outcomes of Students Participating in the Experimental Study

The research team directly monitored the two control and experimental classes, starting by participating in class observation, collecting data, reporting learning outcomes, taking assessment tests, and summarizing scores. The WGCTA test results for the control and experimental classes are shown in Figure 3.

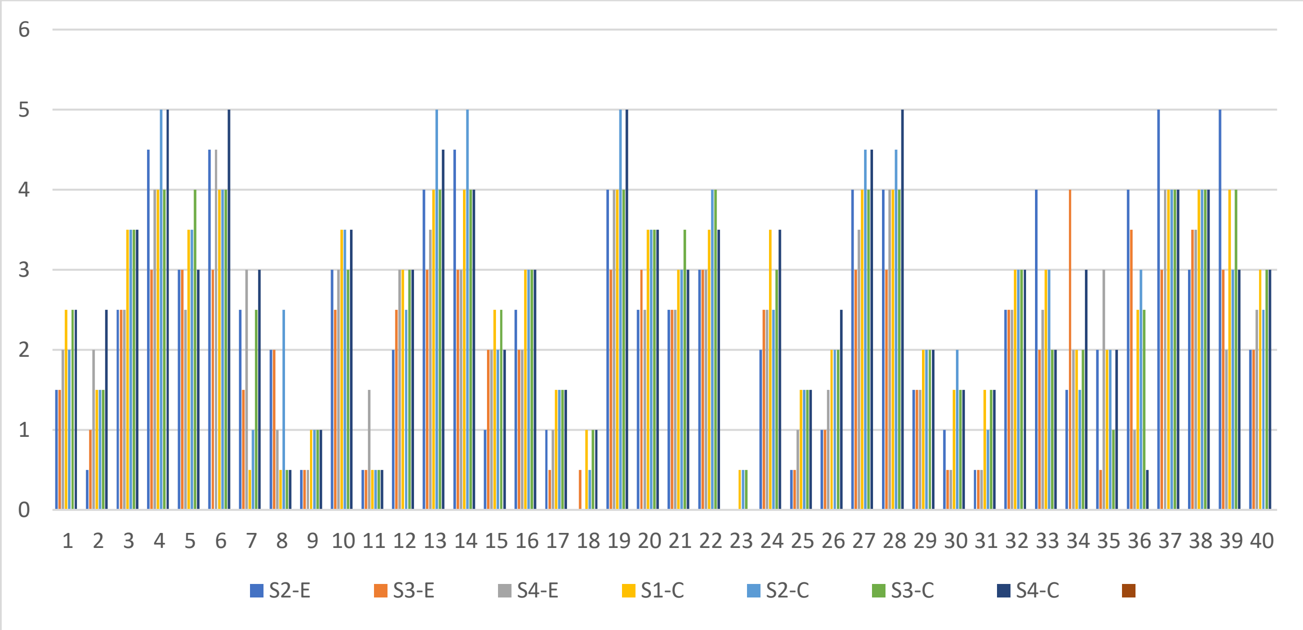

Figure 3.
There was a statistically significant difference between the problem-solving students' skills in real and control classes.

RQ1. Inference Skills (S1): The experimental class (S1-E) had a higher average score than the control class, reflecting students' ability to reason. Interpretation and group discussion activities helped the students gain a deeper understanding of the problem to be solved. The stability of the scores showed that most students achieved a similar level of understanding with the support of PBL. The control class (S1-C) had lower and more scattered scores than the experimental class, showing the limitations of traditional teaching methods in helping students reason during the problem-solving process, evaluate inferences in problem situations, and propose and implement solutions.

Skill S2 (Recognition of Assumptions): Experimental class (S2-E). Students in the experimental class scored significantly higher, reflecting their ability to recognize assumptions related to the problem and connect elements to make hypotheses about climate change. The recognition of the consumption discussion activity helped students develop this skill. The control class (S2-C), which scored lower, showed that students had difficulty recognizing assumptions connecting knowledge. This may be due to a lack of practical activities or opportunities for students to apply their knowledge to real-life situations.

S3 (deductions) skill. The experimental class (S3-E), which scored significantly higher than the control group, demonstrated the ability to propose creative and feasible solutions to problems. Students used the recognition of assumption skills from S2 to identify the problem and propose solutions, such as analyzing the phenomenon of climate change in life and deducting its causes. Recognition of Assumptions encourages the proposal of different problem-solving ideas, which facilitates the development of this skill. The control class (S3-C), which scored lower and more scattered, showed a deficiency in deduction ability, proposing solutions to the problem. Students may have difficulty converting theory into practical ideas.

S4 (Interpretation) skills: The experimental class (S4-E), which scored highest in experimental learning, reflected the ability to analyze the proposed solutions and evaluate their effectiveness. This process helped students develop critical thinking skills and the ability to optimize their solutions. The control class (S4-C), which scored lower, showed that students had fewer opportunities to practice and evaluate the solutions. This limited the students' ability to connect knowledge.

The overall comparison between the two classes shows that the experimental class scored higher on all four skills, especially S3 and S4. This proves that the PBL method not only helps students understand the problem, but also develops the ability to analyze, propose solutions, and implement ideas effectively. The control class scored lower in all skills, with a clear difference between S3 and S4. This indicates that traditional teaching methods find it difficult to fully develop students' problem-solving skills.

To visualize the results of the students' skill assessment, we randomly selected a group of six students from the control and experimental classes and plotted the results of the divergent thinking skills assessment using a radar chart. We examined how PBL impacts these skills of middle school students (see chart in Figure 3)

According to Cleveland and McGill [24] radar charts are an effective data visualization method when users need to evaluate the overall comparison rather than focus on individual criteria. This is suitable for educational research, where students' critical thinking skills must be compared across multiple dimensions through PBL. Radar charts provide a visual view of data, making it easy for analysts to identify trends and anomalies. Radar charts display multiple criteria simultaneously so that viewers can visually compare and analyze them [25]. The criteria are arranged in a concentric axis form, allowing for a correlation assessment between them and identifying strengths and weaknesses in each subject [26]. Clearly identifying criteria for improvement helps optimize teaching and learning methods [27]. Radar charts are suitable for assessing students' skill improvement before (E-group) and after (C-group) participating in the PBL trial [28].

We randomly selected a group of six students from the control and experimental classes and plotted them using a radar chart to examine how PBL affects the critical thinking skills of middle school students (see Figure 4).

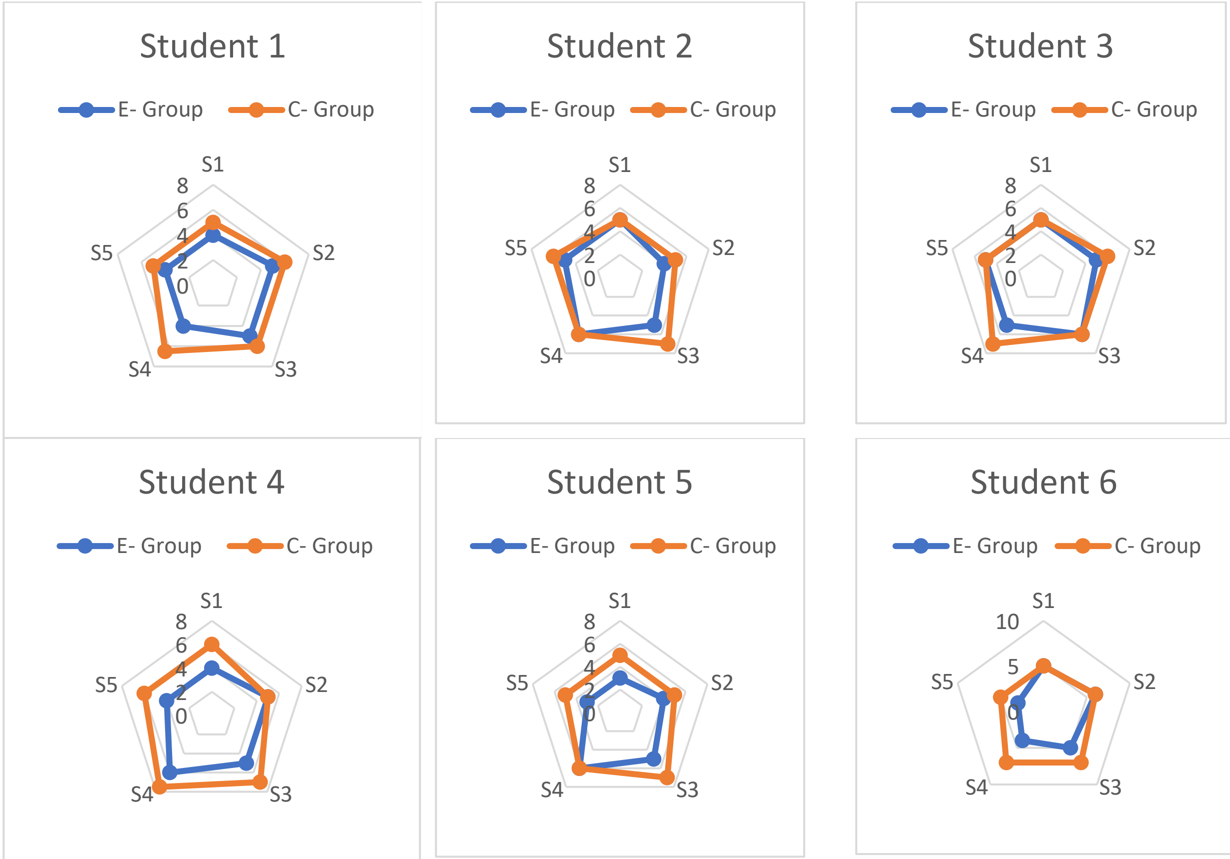

Figure 4.
Graph showing the skills of two groups of students (E- Group, C- Group)

RQ1: Analysis of the radar chart area shows that the E-Group has a larger radar chart area, which means that students in this group have more even development in all criteria for assessing critical thinking. The C-Group has a smaller area, showing that students learning using the traditional method have not yet fully developed their critical thinking. Students in the E-Group showed the most obvious improvement in skills S3 and S4, reflecting their level of progress in developing hypotheses and arguments. Deduction skill (S3): The E-Group had higher scores in proposing creative solutions and making more reasonable inferences. Analysis and evaluation of solutions (S4): Students in the experimental group had the ability to synthesize information and evaluate options better than the control group.

Table 3.
Results of Pearson correlation analysis.

Pt_Lock			**Interpretive**	**Analysis**	**Inference**	**Evaluation**	**Self-Regulation**
PT_Lock	Pearson Correlation	1	0.420**	0.320**	0.431**	0.369**	0.517**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
	N 240	240	240	240	240	240	240
Identify the Problem	Pearson Correlation	0.440**	1	-0.031	.093	-0.081	0.036
	Sig. (2-tailed)	0.000		0.632	0.140	0.189	0.469
	N 240	240	240	240	240	240	240
Research and Analyze the Problem	Pearson Correlation	0.340**	-0.031	1	-0.042	0.016	0.076
	Sig. (2-tailed)	0.000	0.610		0.467	0.764	0.145
	N 240	240	240	240	240	240	240
Propose a Solution	Pearson Correlation	0.451**	0.090	-0.046	1	0.037	.035
	Sig. (2-tailed)	0.000	0.150	0.477		0.558	.563
	N 240	240	240	240	240	240	240
Implement the Solution	Pearson Correlation	0.379**	-0.083	0.018	0.037	1	-.006
	Sig. (2-tailed)	0.000	0.187	0.784	0.568		.914
	N 240	240	240	240	240	240	240
Evaluate and Respond	Pearson Correlation	0.462**	0.032	0.091	0.072	0.001	1
	Sig. (2-tailed)	0.000	0.612	0.147	0.242	0.964	
	N 240	240	240	240	240	240	240

In addition, the experimental group also showed significant progress in skills S1 (inference) and S5 (Evaluation of Arguments), indicating that their ability to evaluate evidence and distinguish between reasonable and unreasonable information improved. The total area difference between E-Group and C-Group was about (4295.0 area units), reflecting a fairly good development in students' critical thinking when teaching PBL.

To examine the relationship between the stages of PBL and the factors affecting students' critical thinking skills, we used IBM SPSS software to analyze the Pearson correlation (see Table 3).

RQ 2: Pearson's correlation analysis (Table 3) shows that there is a relationship between critical thinking skills and PBL. Specifically, self-regulation vs. evaluation (r = -0.006) showed a very small negative correlation, indicating that the ability to self-regulate thinking does not significantly affect the ability to evaluate arguments. This may be because argument evaluation is a skill that needs direct instruction rather than relying solely on self-regulation. Inference vs. Analysis (r = -0.042) showed a very small negative correlation, indicating that inference ability is not significantly related to analysis skills. This may be because students can infer from facts without deeply analyzing their logical structures. Interpretive vs. Evaluation (r = -0.081), a slightly negative relationship, indicates that the ability to interpret data does not mean being able to evaluate arguments well.

General comments: The relationship between critical thinking skills and PBL is uneven; some skills have a strong relationship with PBL (Self-Regulation, Inference), while other skills, such as Analysis and Evaluation, have a weaker relationship.

The relationship between critical thinking skills, specifically self-regulation versus analysis (r = 0.076), a positive but very weak relationship, suggests that self-regulation does not significantly influence analytical skills. This may be because analysis requires a systematic approach, whereas self-regulation involves individual reflections. Interpretive vs. Analysis (r = -0.031), a correlation coefficient close to zero, suggests that there is no clear relationship between interpretation and analysis skills. This may be because students can interpret data without necessarily analyzing their causes or effects in depth. The nearly insignificant relationship between inference and evaluation (r = 0.037) suggests that inference skills are not strongly related to argument-evaluation skills. Students can make inferences based on facts, but cannot necessarily evaluate the reasonableness of an argument.

Table 4.
Results of confirmatory factor analysis (CFA).

	Estimate (Standardized Regression Weights)	ModelFit						CR	AVE	MSV	Square Root of AVE
		CMIN/df	GFI	CFI	TLI	RMSEA	PCLOSE				
DL_Unp	0.869 – 0.912	1.321	0.912	0.982	0.981	0.033	1.000	0.955	0.778	0.010	0.882
DL_CDig	0.840 – 0.887							0.927	0.750	0.008	0.866
DL_Ex	0.802 – 0.881							0.937	0.714	0.010	0.845
DL_Bmp	0.806 – 0.894							0.922	0.731	0.007	0.855
DL_Tes	0.868 – 0.877							0.957	0.786	0.008	0.886

RQ3: The results of the CFA (Table 4) show a high fit with the actual data, while ensuring the reliability and validity of the scale. CMIN/df (Chi-square/df): 1.321 (< 2), indicating that the model was not too complicated and fit the actual data. (Goodness-of-Fit Index): 0.922 (> 0.9), indicating a good fit between the model and data. The Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) both reached 0.982 (> 0.9), indicating that the theoretical model fit the empirical data very well. RMSEA (Root Mean Square Error of Approximation): 0.030 (< 0.05), indicating that the deviation between the theoretical model and the data was very small. Composite Reliability (CR): Average 0.939 (> 0.7), demonstrating the high reliability of the scale. Average Variance Extracted (AVE): From 0.739 to 0.785 (> 0.5), it has good convergence according to the criteria of Fornell and Larcker [29], proving that the indicators in each factor measure the same concept. The GFI = 0.912 and AGFI = 0.908 indices both exceeded the threshold of 0.9, indicating good agreement between the theoretical model and the actual data, corresponding to the requirements of Schumacker and Lomax [30].

At the same time, CFI = 0.982 and TLI = 0.981 indices were both above 0.9, indicating that the model of the relationship between PBL and critical thinking (Figure 1) was reliable. RMSEA = 0.020 and PCLOSE = 1.000 did not show a significant deviation in the model, achieving a good fit, according to the criteria of Hu and Bentler [31]. Regarding the composite reliability, the average CR reached 0.949, far exceeding the acceptance threshold of Nunnally and Bernstein [32] of 0.7, demonstrating the high reliability of the scales.

2. Conclusion

This study provides empirical evidence supporting the effectiveness of PBL in improving the critical thinking skills of middle school students. Through a quasi-experimental design, students in the PBL group demonstrated significant improvements in key critical thinking dimensions—inference, deduction, assumption recognition, interpretation, and argument evaluation—compared with their peers in traditional instruction. This study confirms that PBL creates an interactive and inquiry-oriented learning environment that fosters students' ability to analyze problems, generate hypotheses, and critically evaluate information. An important contribution of this study is the validation of the Watson-Glaser Critical Thinking Assessment (WGCTA) as a reliable assessment tool for measuring critical thinking in middle school students in a PBL context. Confirmatory Factor Analysis (CFA) results (CFI = 0.994, RMSEA = 0.020) showed a strong model fit, supporting the appropriateness of the WGCTA for middle school educational contexts. This finding addresses an important gap in research on the measurement of critical thinking in young students engaged in active learning models such as PBL. The study was conducted with 240 ninth-grade students from two middle schools, which may limit the generalizability of the findings to other grades, educational settings, or cultural contexts. A larger and more diverse sample across multiple schools and regions increases the robustness of the results. This study measured improvements in students' critical thinking over a relatively short period. However, the development of critical thinking is a long-term process, and future research should conduct longitudinal studies to examine the lasting effects of PBL on students' cognitive development.

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Appendix 1.
Lesson Plan: Problem -Based Learning on Climate Change.

1. Learning Objectives
   - Understanding the causes, consequences, and human impacts of climate change.
   - Develop critical thinking, problem-solving, research, and collaboration skills.
   - Propose and implement practical solutions to mitigate climate change at the local level.

2. PBL Teaching Process

Stage 1: Identify the Problem

Objective:
- Students recognized climate change as a real-world and urgent issue.

Activities:
1. Introduction with real-world scenario
   The teacher shows short videos or images depicting the effects of climate change (melting ice, forest fires, and rising sea levels).
2. Group discussion
   Students discuss:
   - What do they observe in the videos or images?
   - How does climate change affect nature and human lives?
   - What actions could be taken to mitigate this impact?
3. Problem statement & research questions
   Students formulated research questions related to climate change.

Stage 2: Research and Analyze the Problem

Objective:
The students investigated the causes, impacts, and existing solutions to climate change.

Activities:
1. Gather information
   - The teacher guides students in collecting data from scientific reports (IPCC, NASA, and UN), environmental websites, and news articles.
   - The students worked in groups to examine different aspects.
     + Main causes of climate change.
     + Effects on people and ecosystems.
     Policies and measures implemented globally.
2. Analyze data
   Students evaluated the credibility of the sources and compared the findings.
3. Preliminary reports
   - The findings are presented for each group.
   - Class discussions with peer feedback and critical questions.

Stage 3: Propose a Solution

Objective:
Students develop creative and feasible solutions to combat climate change.

Activities:
1. Brainstorming solutions
   Each group generated the following ideas.
   + Using renewable energy sources.
   + Reducing the carbon footprint (eco-friendly lifestyle, waste reduction, and water conservation).
   Implementing local action projects (tree planting, awareness campaigns, and waste management initiatives).
2. Developing an action plan
   - Students selected one solution and created a detailed action plan.
   - Analyze strengths, weaknesses, opportunities, and threats (SWOT analysis).
3. Presenting solutions
   - The groups then presented their solutions.
   - Class feedback and suggestions for improvement.

Stage 4: Implement the Solution

Objective:
The students applied the proposed solutions to real-life situations or classroom projects.

Activities:
1. Pilot implementation
   - If the solution involves behavioral changes (e.g., reducing plastic use), students will implement it for a week.
   - If it involves community action (e.g., tree-planting and awareness campaigns), students organize an event.
2. Data collection & documentation
   - Students tracked their progress and collected data before and after implementation.

Stage 5: Evaluate and Respond

Objective:

The students assessed the effectiveness of their solutions and made improvements.

Activities:

1. Evaluate outcomes
   - Comparison of before-and-after results from collected data.
   - The positive impacts and limitations of these solutions are discussed.
2. Reflection & improvement

   These groups have proposed adjustments or alternative solutions.
3. Community sharing

   Students create infographics, short videos, and blog posts to share their findings with the school or the local community.
4. Final class reflection

   The teacher facilitated the discussions.

   + What did you learn?
   + How will you continue to contribute to climate change?

Appendix 2.

Sample Critical Thinking Assessment Questions.

Part 1. Inference (S1)

scientific report states that the average global temperature has increased by 1.2°C over the past 100 years. What consequences do you think could this lead to?

A.However, it had no significant impact on the environment.

B. Sea levels may rise and cause flooding in many places.

C. Droughts and forest fires may decrease because of increased temperature.

D. No conclusions can be drawn because the information is insufficient.

If a country reduces its carbon emissions by 50% over the next 10 years, this will help prevent climate change. Why?

Part 2. Recognizing Assumptions (S2)

An electric car company claims that using electric cars causes no harm to the environment. Do you think that this statement is reasonable? Why?

Some people believe that climate change is caused by natural causes, and not by humans. Did you agree with your view? Explain your reasons.

Part 3. Deduction (S3)

Based on the following information: "The amount of ice in the Arctic is decreasing every year.” Which of the following statements is true?

A. All animals in the Arctic are expected to become extinct in the next 10 years.

B. Sea levels can increase and affect coastal areas.

C. Ice in Antarctica disappeared immediately.

D. There is no connection between ice melting and sea level.

Part 4. Interpretation (S4)

Scientific reports show that CO_2 levels in the atmosphere have reached their highest levels in 800,000 years. What do you think these data mean to the environment now and in the future?

One study showed that rainfall decreased in some areas, whereas other areas experienced more severe flooding. Is this inconsistent with the climate change? Explain.

Part 5: Evaluation of Arguments (S5)

An environmental activist says, "If everyone in the world used public transport instead of private cars, climate change would end." Do you agree with your statement? Why?

Some argue that only governments and large organizations can help reduce climate change, whereas individuals cannot. Do you agree? Explain.