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Constructing an integrated problem-based and collaborative learning model: Empirical research on the development of fourth-grade primary school students' problem-solving and teamwork skills in mathematics class

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ABSTRACT

In the 21st - century skills - oriented education, this study aims to bridge the gap in traditional mathematics teaching, which often addresses teamwork and problem - solving skills independently. It focuses on designing and assessing an integrated instructional model using Problem - Based Learning (PBL) via Collaborative Learning (CL) to equip students with integrated skill sets. A quasi - experimental single - group pretest/posttest study was carried out with 30 fourth - grade students. They participated in well - designed instructional activities, and their skills were measured using standardized instruments before and after the intervention. The results showed significant improvements in students' teamwork and problem - solving skills. Teamwork skills had a mean increase of 5.17 points ($p < 0.05$), and problem - solving skills improved by 3.10 points ($p < 0.05$). PBL and CL are effective in engaging students in divergent thinking, collaborative learning, and solving real - world problems. This empirically - validated instruction provides educators with a roadmap to develop key competencies for students' academic and career success, offering solutions to improve primary mathematics education for all - round student development.

Contribution/ Originality: This study integrates PBL and CL in primary math teaching. It's novel as it assesses their combined impact on fourth - graders' problem-solving skills and teamwork skills, filling a research gap.

1. INTRODUCTION

Teamwork and problem-solving skills are developed in the fourth-grade mathematics courses to ensure the children are well prepared for the challenges they will encounter in the 21st century and their analytical and creativity skills are enhanced (Sahin & Eraslan, 2017). The mathematics curriculum in primary schools emphasizes the ability to use mathematics to solve problems in daily lives, prepare individuals, and work efficiently as a team (Arrahim, Sugiharti, & Damayanti, 2020). Mathematical models and techniques of modeling are used in problem analysis and will also get some of the students involved (Alibekova, Ashirbayev, Ashirbayeva, & Altynbekov, 2024). Through the application of some tools such as model-eliciting activities, model-eliciting tasks, and the nature of mathematics tasks, the students can improve their skills and demonstrate a new type of mathematical thought that will be a benefit to their future life after school (Deniz & Kurt, 2022). It was also noted that students have improved in their ability to solve mathematics problems and have gained more critical thinking skills from the models TAI

and the group formation strategy Emergenetics (Andari, Risnawati, Andriani, & Habibi, 2023). These approaches allow pupils to work in teams, synthesize their thoughts, and solve mathematical problems. In general, fourth-grade mathematical courses should enhance teamwork and problem-solving skills as this results in the students becoming competent problem solvers in later life. Teamwork and problem-solving skills can be enhanced in fourth-grade mathematical courses through various approaches. One approach is the implementation of the Team Assisted Individualization (TAI) learning model. This model has been demonstrated to encourage the students' reasoning in mathematics (Andari et al., 2023; Mahendra, Husamah, & Budiono, 2023). Another approach is the use of the PBL model, specifically those in which students show mathematical connections and gain concept understanding (Arbo & Ching, 2022). Moreover, the Student Team Achievement Division (STAD) format of cooperative learning is another characteristic feature. This style has been engaging for students in terms of changing their views in learning the subject of math and cognitively coming to the mastery (Dewi, Rahmah, & Hidayah, 2022). These research studies defend the course of existing projects, but the existing research studies have furnished evidence of the performance of these methodologies in improving mathematical integration contexts of problem-solving skills among fourth-grade students. Teamwork, a pivotal factor in mathematical learning, raises enduring attention to the board in all stakeholders. It taps into communication, interaction, and teamwork that undoubtedly contribute to students' top performance and learning outcomes (Omar & Plumb, 2023). As claimed, such courses are useful for the respective discussion because of their steep learning curves. We are currently looking at mathematics-intensive and research methods courses (Brannon, Zhan, & Zhang, 2022). Team based learning intervention programs have an affirmative effect on student's acceptance of lectures, acquiring important subject matters, teamwork bonding, academic support, and collective efficacy (Espino, Núñez, Chávez, & Ibañez, 2020). Didactic strategies based on the concepts of teamwork and scientific debates in virtual groups are found to promote teamwork and collaborative learning (Dincă, Luştrea, Oniţiu, Craşovan, & Berge, 2021). These specifics and teaching methods determined that "Master-Apprentice" association raised students' motivation. It made students correct the wrong notions adopted in learning, and peer discussions were helped this way (Sa'diyah, Muchyidin, & Izzati, 2022). However, it should be considered that teamwork does the biggest part in math education by creating opportunities to connect, properly communicate, and address people's problems. Problem-solving skills are important for students. Shorter processes lead to creativity and innovation. High school students will find a way not only to continue doing well in school but also to succeed at work and be more creative (Adeoye & Jimoh, 2023). Human learners link their creative abilities with problem-solving skills by recognizing serious problems and developing better solutions to make their methods work (Lasaiba & Arfa, 2023). Self-readiness, learning creativity, and learning motivation also contribute to problem-solving skills (Özpinar & Arslan, 2023). Students display a reasonable level of problem-solving skills. However, these skills are affected by variables such as the level of education, gender, GPA(Grade Point Average), and mathematics grades (Wang, Peng, & Li, 2022). An emphasis encased in programs of vocational training is placed on problem-solving skills. It provides important skills necessary for various societal sectors (Häkkinen et al., 2017). Moreover, problem-solving skills introduce critical aspects required by environmental regarding problems, which can be developed through environmental literacy. Thus, solving the problem meant that just owning an aptitude for evaluating, thinking, comparing, and creating solutions forms an essential background for students to handle all types of challenges at work, in school, or in life.

Conclusively, this paper increasing emphasis on teaching activity models that harmonize with PBL and collaborative learning and evaluate the efficiency of the model through a single group's pre-post-test quasi-experimental design. These aims focus on the ceilings of PBL, which exhibits many naturally unique aspects that can be integrated, such as problem-solving skills and teamwork skills, in the context of mathematics classrooms. This study also presents an empirical basis for determining the integration of problem-based and collaborative learning instructional methods, which can well equip educators to understand more deeply and apply these methods to realize the comprehensive system of students suitable for modern society.

2. LITERATURE REVIEW

Different researchers come with distinctive perceptions on teamwork skills. Lacerenza, Marlow, Tannenbaum, and Salas (2018) contend that teamwork skills are a formation of abilities that individuals in a team should possess. This would help attain common goals. These include communication, conflict-solving, leadership, task allocation, and reception of feedback. From this standpoint, teamwork skills entail a special ability required in the different stages of team processes. They are also crucial for ensuring that the team moves forward to achieve its objectives. Schartel Dunn and Nisbett (2020) argue that teamwork skills are a comprehensive and evolving competence that does not only include task execution but also social interaction among students. This suggests that communication and the task execution are not among the only components of teamwork. Building positive interactions and relationships among the members is as crucial as any other component. This underlines the organic feature of the team as a unit working together on various dimensions. Countless research has established that accentuated curriculum design has a great contribution in sharpening students' teamwork skills. As an illustration, Barker (2021) unveiled from the study conducted on undergraduate mineralogy courses that the presence of problem-based learning (PBL) and feedback systems played a pivotal role. Such practices were found to remarkably increase teamwork skills of the students. The PBL model utilizes problems to motivate students to work together. This obliges them to employ communication skills to share ideas, conflict resolution skills to solve different opinions, leadership and task distribution skills to effectively arrange work, and feedback skills to mentor members and groups towards continuous intention. These activities widely strengthen and enhance teamwork skills of the individuals. Moreover, according to Schartel Dunn and Nisbett (2020) business schools urge systematic teaching of teamwork skills in courses to minimize students' mere participation in team events with a slackened attitude of observation and inactivity. Systematic curriculum design is therefore significantly required. This means that students do not only have to be distributed into groups to attain common tasks. They must be taught teamwork skills through a thoughtfully planned and organized instruction that also contains training exercises to develop those skills. This methodology permits students to acquire a holistic comprehension of the essence of teamwork skills. Practice to them confidence in the new skills hence provides excellent success rate in teamwork skills development.

Problem-solving is one of the success outcomes. It is one of the most highly recognized aspects of early childhood learning (Cornoldi, Carretti, Drusi, & Tencati, 2015). Its importance cannot be underestimated and has even become a key indicator for evaluating educational outcomes, as emphasized by Meißner, Greiff, Frischkorn, and Steinmayr (2016). In educational settings, students need to deeply explore problem situations, organize and integrate various pieces of information, and seek precise solutions (Meißner et al., 2016). This process includes not only their knowledge acquisition but also the way in which the learning is applicable to general life problems. The acquisition of this aptitude has profound implications for them. It prepares them for facing future societal challenges. Beliefs about what constitutes problem-solving skills have varied considerably. From the perspective of Daryanes et al. (2023) this ability hinges first of all on being decisive. The evaluation of various lines of action is essential after making decisions when individuals face issues. Scholars like Karayol and Temel (2018) and Yilmaz, Ozana, and Güven (2018) are convinced that problem-solving skills gradually develop through a process consisting of finding new obstacles and managing to overcome a whole range of them. These constructs are not only related to solving problems that they are not aware of. Experiences in resolving those issues are mainly the determining aspect. Scientists such as Solaz-Portolés and Sanjosé (2007) and Rittle-Johnson, Star, and Durkin (2009) point out that problem-solving skills are made up of several activities. These actions are cognitive, behaviorist, and attitudinal characteristics that are affected by some interacting factors. These include the practical context, individuals' knowledge, and experiences. However, scholars with different views are unanimous when they point out that problem-solving skills are educable and modifiable through training and experience. Such skills reflect the complex architecture that is strongly sensitive to the specific contextual parameters. Thus, these values indicate that

teachers should not act in accordance with difficulties when training students in problem-solving skills. This will, in turn, contribute to adequately catalyzing problem-solving skills among the majority of students. Indeed, this will bring students out as experts in their respective society, hence, the capability of managing different situations at different places in time. A firm foundation will be set for lifelong growth of these students. Problem-Based Learning (PBL) is basically an educational approach that is explained by educators as a method that puts the learner in the center stage. This approach involves looking at the environment we live in and solving real-life problems. Problem-Based Learning (PBL) does not use traditional methods of memorizing facts. Instead, students take part in group problem-solving tasks. It helps them to identify the problem, develop solutions, and write a learning theory (Hmelo-Silver, 2004). This technique promotes team spirit. This happens as learners come up with shared ideas. This facilitates task allocation and consensus building among the students, ultimately boosting collaboration abilities (Suryanti & Supeni, 2019). Additionally, this approach enables students to broaden their problem-solving and critical thinking abilities by dealing with extraordinary and indefinite problems (Ali, 2019). Such works prove PBL to be an effective method and a strategy for developing skills essential to achieving academic and career success. It is unfortunate that Collaborative Learning (CL) is frequently and wrongly perceived as positioning students for either face-to-face or virtual discussions of an assignment during individual time, or as some students doing the assignment themselves. Those who have finished it earlier, with those who have not, but with the assurance that they will help the rest to finish it as well. Even more, it is sometimes viewed as having a few students do the bulk of the work while the others just attach their name to the final report (Klemm, 1994). However, Collaborative Learning (CL) is the instructional approach that tactically links large, multi-teamed groups together over a longer period (usually two or more) to work collectively toward the common aim of sharing and achieving knowledge. CL is most commonly understood as cooperative or participative learning in which students think collectively and share knowledge even in a digital learning environment (Koivuniemi, Järvenoja, & Järvelä, 2018; Le, Janssen, & Wubbels, 2018). To put it differently, Collaborative Learning highlights the core value of inclusivity among students because of their interactive nature. They learn from each other (Gillies, 2019). What is unique to the Collaborative Learning environment is that the learners are motivated to express the inquiry process itself, clarify in-depth, share perspectives, add new information, and recommend solutions (Matuk & Linn, 2018). An examination carried out from Fall 2015 to Spring 2018 reviewed 261 learning teams by self-assessment together with peer and team evaluations. For excellence in teamwork, most students excelled in task behaviors and attitudes (Farland & Beck, 2019). Problem-solving skills coping with new and unprecedented situations are another feature that was further researched in an experimental study. It explored the effect of the Local Wisdom-Based ELSII Learning Model (LWB-ELSII) on students' problem-solving skills (PSS). The study was conducted on 56 prospective Islamic teachers in Mataram State Islamic University. The data collection tool was the PSS Essay Test (PSET). This analysis had a statistically significant finding that showed an improvement in students' problem-solving skills (PSS) for this local wisdom-dependent project (Fadli, 2020).

Teamwork and problem-solving skills are regarded as the most common skills nowadays by almost everyone, yet not every person possesses them. There is enough evidence to suggest that problem-based learning (PBL) and collaborative learning are effective strategies that can develop those skills among students. Nevertheless, learning is a rather intricate process, and there is no single tool capable of providing an answer to every problem on the learning canvas. A combination of various teaching strategies is often required to accomplish optimum results. Previous research has predominantly focused on the application of individual teaching methods, overlooking the potential benefits of integrating multiple approaches. To address this gap, this study aims to design an instructional model that combines the strengths of problem-based learning and collaborative learning. This model will be implemented in primary school mathematics courses to examine its impact on students' teamwork and problem-solving skills.

3. RESEARCH METHODOLOGY

3.1. Research Design

This investigation created an educational activity framework informed by elements of problem-centered learning and cooperative learning approaches. A single-group pretest-posttest experimental study was consequently devised, which found its number derived from the instructional model for activity. This study was conducted in a public school in Chengdu. A random sample of 30 students was selected from a group of 197 students studying in fourth grade and given the opportunity to participate in the research. Due to the designed instructional model, the study entailed the preparation of 15 teaching management plans. In the quasi-experimental study, students' teamwork and problem-solving skills were pretested by two instruments, namely, the Teamwork Skills Checklist and the Problem-Solving Test, for 30 students. Moreover, the 30 students were taught over 15 teaching management plans. Teamwork and problem-solving skills of 30 students were post-tested through the Teamwork Skills Checklist and the Problem-Solving Test. Throughout the study, a paired sample t-test analysis from the pretest and posttest scores of the experimental group was done using the SPSS package.

3.2. Research Objectives

The purpose was to propose the effect of an instructional activity model on grade four students' rather inconvenient teamwork skills and problem-solving ability. The primary intention of the research indicated that the model design and the quasi-experimental strategy are primarily the key issues that need to be analyzed. Specifically, this involves an instructional activity model based on problem-based learning and collaborative learning. The model was aimed at examining the presence of its impact on social skills and general problem-solving skills.

3.3. Research Sample

The populations for research are taken from 192 Grade 4 students in Chengdu Xiti Street Primary School, China, through the cluster random sampling technique. Of this number, 30 students are selected as the research sample. Their distribution to the experimental group is handled later among others.

3.4. Research Hypothesis

The students who engaging in instructional activity based on problem-based learning and collaborative learning revealed higher post-test scores of teamwork skills and problem-solving skills than pre-test scores.

3.5. Research Instruments

3.5.1. Teamwork Skills Assessment Scale

The Teamwork Skills Assessment Scale was devised to encompass all aspects of the teamwork skills of fourth graders in a mathematical learning environment. The scale includes 12 items, encompassing four main dimensions: Communication, Collaboration, Conflict Resolution, and Collective Problem-Solving. Each item is measured on a 5-point Likert continuum from Strongly Disagree (1) to Strongly Agree (5). Focusing on the Communication aspect, the dimension includes items that focus on students' abilities to express themselves, listen, and question their peers. The Collaboration dimension evaluates the degree to which one acquiesces to equal task shares, the support of teammates, and the adaptability of given roles. Conflict Resolution reflects how disagreements are settled, shared solutions are found, and feedback is equally accepted. Finally, Collective Problem-Solving analyzes students' involvement in brainstorming, planning, and monitoring the solutions. The scale aims to provide educators and researchers with a suitable and standarded measure of the quality of instruction and teamwork skills among primary students. The goal is to inform future changes in educational systems and interventions.

3.5.2. Problem Solving Skills Test Paper

This assessment paper was created to analyze the problem-solving skills of middle-grade students in math. It contains 25 questions competed by multiple-choice format. It touches on elementary math, fractions, multiplication and division, decimals, word problems, geometry, measurement and data, patterns, and algebra. The appropriate cognitive level for fourth-grade students is used in the formulation of questions so that the challenge is also a suitable level for their age and school stage. Each question subsequently gauges multiple dimensions of problem-solving, from analytical thinking to logical reasoning and the real-life application of mathematics. Through a conglomeration of various types of questions, the test development provides a well-rounded assessment of the capabilities that students show in the comprehension, analysis, and resolution of the problems of mathematics. This systematic approach is a guarantee that educators will identify the specific areas where the students obtain high or, at the same time, fall short. This can provide educators with solid evidence that points out specific needs for further development.

3.6. Data Collection

The assessment time for the tiered-test is between the first and last stages of the instructional management plan. The assessment period for the scale is before the first instructional management plan and after the completion of the last plan.

3.7. Data Analysis

The study employed Paired Samples T-Test to analyze the scores of teamwork skills and problem-solving skills in the experimental group, thereby testing the first hypothesis: "The students who engaging in instructional activity based on problem-based learning and collaborative learning revealed higher post-test scores of teamwork skills and problem-solving skills than pre-test scores".

3.8. Ethical Affirmation

This research project, titled "*An Instructional Activity to Enhance Teamwork Skills and Problem-Solving Skills in Mathematical Learning for Fourth-Grade Students Based on Problem-Based Learning and Collaborative Learning*" has been ethically approved by the Research Ethics Committee of Nakhon Phanom University, Thailand. This ethical approval, with the reference number HE2568 and the record number 25/2568, was issued on November 13, 2024, and is valid until November 12, 2025.

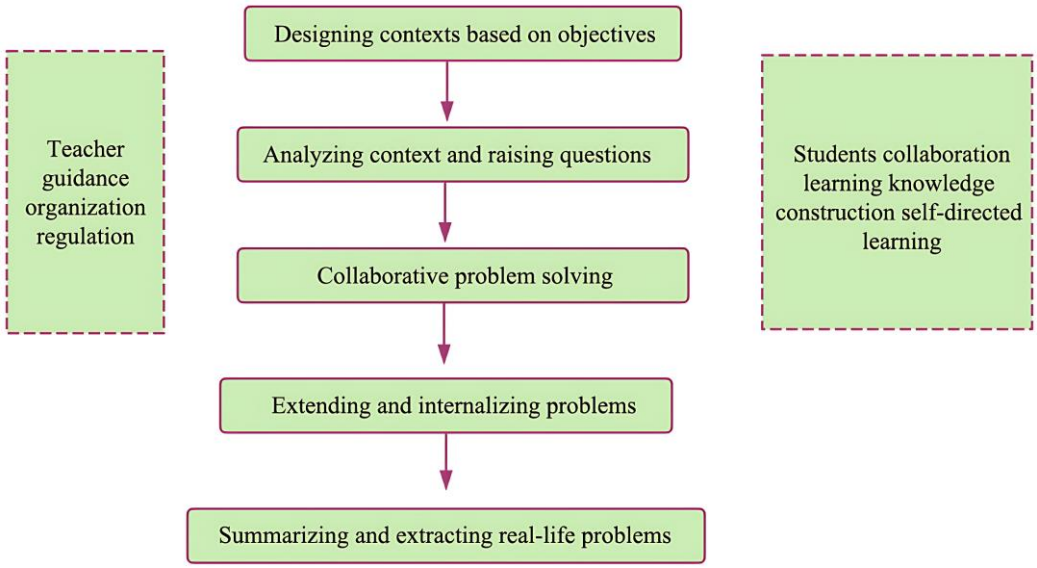

Figure 1. Illustrates instructional activity model based on PBL and CL.

4. RESULTS

4.1. Instructional Activity Model

This study integrates the characteristics of problem-based learning and collaborative learning to design a teaching activity model (as shown in Figure 1). The teaching model is divided into three phases: the first phase involves scenario introduction, where the teacher constructs a learning context and presents a problem for students to independently solve. The second phase is the first collaborative learning session, where students work in groups of five to solve the second problem collaboratively. The third phase is the second collaborative learning session, also conducted in groups of five, to collaboratively solve the third problem. The specific operational procedures are detailed in Table 1.

Table 1. Instructional activity model flow chart.

Stage	Assignments
Designing contexts based on objectives	Teacher tasks:
	(1) Identify the learning objectives for the lesson.
	(2) Create real-life scenarios or contexts that align with these objectives.
	(3) Ensure the contexts are engaging and relevant to the students' experiences and knowledge level.
	(4) Prepare any necessary materials or resources to support the context.
	Student tasks:
	(1) Engage with the context provided by the teacher.
	(2) Discuss the context with peers to understand its relevance and implications.
	(3) Identify any initial thoughts or questions about the context.
Analyzing contexts and raising questions	Teacher tasks:
	(1) Guide students to carefully read and analyze the context.
	(2) Encourage students to identify key information and concepts within the context.
	(3) Facilitate discussions that help students formulate meaningful and relevant questions based on the context.
	Student tasks:
	(1) Read and analyze the information presented in the context.
	(2) Identify and highlight important details and data.
	(3) Work in groups to raise questions that arise from their analysis.
	(4) Share their questions with the class and engage in a discussion to refine and prioritize them.
Collaborative problem solving	Teacher tasks:
	(1) Organize students into collaborative groups.
	(2) Provide guidance and support as students work through the problems.
	(3) Encourage the use of various problem-solving strategies and approaches.
	(4) Monitor group dynamics and ensure all students are participating.
	Student tasks:
	(1) Work collaboratively to solve the problems raised in the previous step.
	(2) Apply mathematical concepts and strategies to find solutions.
	(3) Discuss different approaches and solutions within the group.
	(4) Record their thought processes and solutions.
Extending and internalizing problems	Teacher tasks:
	(1) Facilitate a class discussion where groups present their solutions and thought processes.
	(2) Guide students to extend their problem-solving skills by exploring related problems or variations.
	(3) Encourage students to internalize what they have learned by reflecting on their problem-solving process.
	Student tasks:
	(1) Present their solutions and thought processes to the class.
	(2) Participate in discussions to extend their understanding and explore related problems.
	(3) Reflect on their problem-solving strategies and how they can apply them in different contexts.
	(4) Internalize their learning by connecting it to prior knowledge and future

Stage	Assignments
	applications.
Summarizing and extracting real-life problems	Teacher tasks:
	(1) Lead a reflective discussion on the entire problem-solving process.
	(2) Ask guiding questions to help students summarize their learning and extract key insights.
	(3) Provide feedback on both the process and the solutions.
	Student tasks:
	(1) Reflect on the problem-solving process and their individual contributions.
	(2) Discuss what they have learned and how it applies to real-life situations.
	(3) Write a summary or reflection of their learning experience.
	(4) Identify other real-life problems that could be solved using similar approaches.

4.2. Hypothesis Testing

The students who engaging in instructional activity based on problem-based learning and collaborative learning revealed higher post-test scores of teamwork skills and problem-solving skills than pre-test scores.

Table 2 presents comparison of pre-test and post-test in the experiment group.

Table 2. Comparison of pre-test and post-test in the experiment group.

Students' scores in different tests	M	SD	t	Df	p
Pre-test of teamwork skills	46.73 points	3.28	23.47	29	0.0000
Post-test of teamwork skills	51.90 points	2.62			
Pre-test of problem-solving skills	19.13 points	7	23.85	29	0.0000
Post-test of problem-solving skills	22.23 points	4.95			

A Paired Sample T-Test was conducted on the same group of participants to determine whether there was a significant difference in the average scores for teamwork and problem-solving skills between the pre-test and post-test measurements. The Paired T-Test results presented below reveal significant differences in scores between the two tests.

For teamwork skills, the results indicated a significant improvement: $t(29) = 23.47$, $p < 0.05$. On average, participants scored higher on the post-test ($M = 51.9$, $SD = 2.62$) compared to the pre-test ($M = 46.73$, $SD = 3.28$). The mean difference (MD) of 5.17 suggests that the intervention had a positive impact on enhancing teamwork skills among the participants. The effect size (d), calculated using the pooled standard deviations, indicates a large effect, following Cohen (1988) guidelines, demonstrating that the intervention led to a substantial improvement in teamwork skills.

Similarly, for problem-solving skills, the Paired T-Test also showed a significant increase: $t(29) = 23.85$, $p < 0.05$. The average scores rose from 19.13 ($SD = 1.81$) in the pre-test to 22.23 ($SD = 1.50$) in the post-test. The mean difference (MD) of 3.10 highlights that the participants' problem-solving skills significantly improved after the intervention. As with the teamwork skills, the effect size (d) was large, indicating a strong impact of the intervention on enhancing problem-solving skills.

The results from both analyses indicate that the implementation of the chiropractic approach in the intervention, which presumably integrated the elements of both team-based learning and inquiry-based learning, significantly enhanced the teamwork and the problem-solving skills of the participants. The large effect sizes, on the other hand, denote that these developments were not only statistically significant but also had practical relevance. Based on this, the students manifested enhanced analytical skills, reasoning skills, and collaboration. Thus, the application of pedagogical strategies used was practical.

5. DISCUSSION

This study demonstrates that the integrated teaching model based on problem-based learning and cooperative learning is an effective method in improving problem-solving and teamwork skills among fourth-grade students in their math curriculum. The findings were positive in enhancing both aspects of teamwork and problem-solving. It was found that teamwork improved by a mean of 5.17, while problem-solving increased by 3.10 points among the students. The fact that they have large effect sizes is additional testimony to the very strong positive impact of the teaching model. This confirms the value of using a combination of PBL and CL teaching methods in strengthening learners' critical 21st-century skills in the upper primary class.

These results are consistent with the earlier research that stresses the role of collaboration and problem-solving skills in learning. To mention one case in particular, the study follows that by Barker (2021) which emphasized the aspect of PBL in the development of teamwork skills through joint completion of tasks. It also extends the findings of Mahendra et al. (2023) by illustrating how integrating PBL and CL is even more beneficial. This work, however, differs from those that previously only focused on PBL (Ali, 2019) or CL (Gillies, 2019) as separate teaching methods. Moreover, the results in overall problem-solving skills go hand in hand with what previous studies revealed (Daryanes et al., 2023; Rittle-Johnson et al., 2009). They found out that applying locally specific context and conduct of inquiry-based activities was effective in raising cognitive abilities. The integrated aspect of this study addresses the critical gap of helping in the acquisition of individual and group skills in a comprehensive manner.

To heighten the proficiency gains of the integrated teaching model, educators have to participate in particular training that helps in developing and presenting PBL and CL exercises. Needed are those who have the ability to steer debates, control the process of interaction, and keep students' attention at the same time. Sukackė et al. (2022) also agree with this statement. The groups must be formed taking into consideration internal diversity of skills and personality traits to increase the level of intercommunication and peer learning. It also factors in gender equity (Graesser et al., 2018). Their compatibility, however, is enhanced by the use of mechanisms like Emergenetics® grouping (Insorio & Librada, 2020). The students should also be included in the process of reviewing and changing the learning methods used to make sure they meet their needs (Mandouit, 2018). Enough and suitable resources, which may include manipulatives, ICT, experiential activities, and real-life situation simulations, should be present for motivation in a learner-friendly environment (Nilimaa, 2023).

This study, though showing positive results, does characterize limitations that attending to would be of great value. To start with, only 30 subjects were involved in this research, coming from one particular school. This, therefore, addresses the issue of the generalization of the findings. Further research has to consider larger and more random samples to guarantee the validity of the findings. Thirdly, the teaching model was mainly assessing the short-term impacts, but at the same time, it omitted the long-term effectiveness. The longitudinal research will give deeper insights into the long-term achievement of PBL and CL. Specifically, the lack of a control group in this study affects the comparison of the integration results with standalone PBL or CL approaches. Hereby, comparative design should be taken into account in future studies to overcome this shortage. While the present assessment tools are practical and give good results, further research in this direction could become sufficient to utilize the qualitative methods, for example, interviews and observational research. Thus, the progress in remedying the shortcomings will inevitably enhance quality instruction to become a comprehensive teaching model and promote its implementation in various settings.

6. CONCLUSION

To sum up, the main idea of this study highlights that the learning approach based on problem-based learning and collaborative learning might form a strong linkage in developing students' math skills in group work and problem-solving in fourth grade. Inappropriate skills can be significantly improved with the help of the produced

results acting as guides for primary school teachers to teach pupils necessary 21st-century competencies. It should be noted that the study has its weaknesses. Nonetheless, it makes a strong foundation for further research on the implementation of integrated models. In light of the outlined major issues, future research should continue on this route, making teaching practices better related to learning outcomes and all learners' development outcomes for their own prosperity.

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Institutional Review Board Statement: The Ethical Committee of the Nakhon Phanom University, Thailand has granted approval for this study on 13 November 2024 (Ref. No. HE2568).
Transparency: The authors declare that the manuscript is honest, truthful and transparent, that no important aspects of the study have been omitted and that all deviations from the planned study have been made clear. This study followed all rules of writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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