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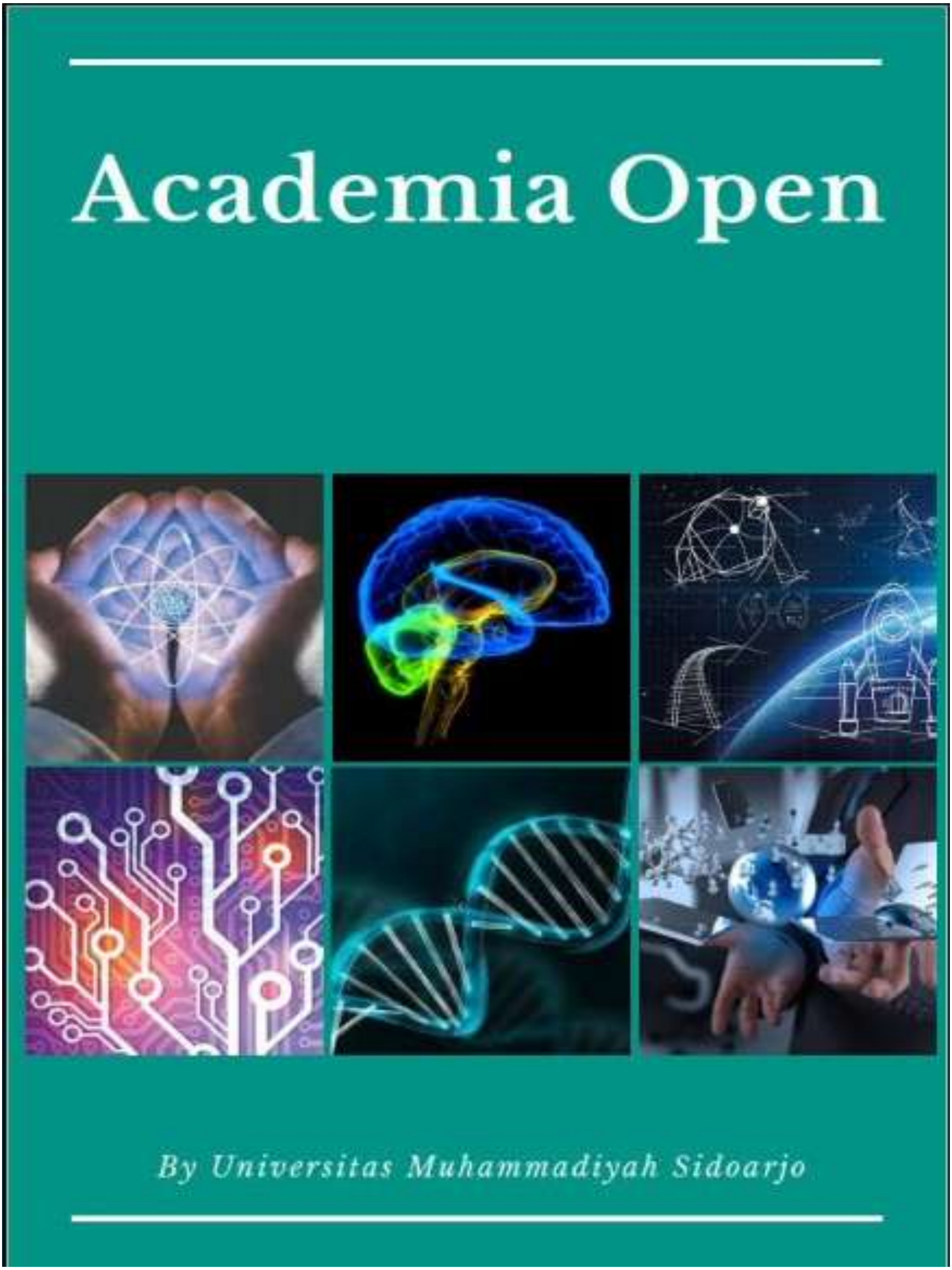

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Technology-Enhanced Cooperative Learning for Mathematical Connection Development: Design and Evaluation of a TPS-Integrated Digital Worksheet: Pembelajaran Kooperatif Berbantuan Teknologi untuk Pengembangan Koneksi Matematis: Desain dan Evaluasi Lembar Kerja Digital Terintegrasi TPS

Endang Wifda Munjiah Gea, wifdagea@gmail.com (*)

Educational Technology, Postgraduate Universitas Negeri Medan, Universitas Negeri Medan, Indonesia

Mukhtar Mukhtar, mukhtar@unimed.ac.id

Educational Technology, Postgraduate Universitas Negeri Medan, Universitas Negeri Medan, Indonesia

Abdul Hamid K, abdulhamidk1958@gmail.com

Educational Technology, Postgraduate Universitas Negeri Medan, Universitas Negeri Medan, Indonesia

(*) Corresponding author

Abstract

General Background: Technology-enhanced learning environments areincreasinglyvital in modern mathematics education to promote student engagement and higher-order thinking. **Specific Background:** Developing mathematical connection ability—the capacity to relate concepts across disciplines and real-world contexts—remains a persistent challenge in secondary mathematics classrooms. **Knowledge Gap:** While previous studies have examined Think-Pair-Share (TPS) cooperative learning and digital worksheets separately, empirical research integrating these elements into a unified design for strengthening mathematical connections is scarce. **Aims:** This study developed a TPS-integrated digital worksheet (E-LKPD) and evaluated its validity, practicality, and effectiveness in fostering students' mathematical connection ability. **Results:** Using the Four-D (4D) development model, the worksheet achieved high expert validation (90%) and practicality (88%) scores; furthermore, students using the digital tool achieved a significantly higher mean score (81.9) compared to those in conventional instruction (63.3), with a statistical significance of $p < 0.05$. **Novelty:** This study uniquely embeds cooperative TPS stages within an interactive digital environment to systematically facilitate students' ability to establish relationships among mathematical ideas. **Implications:** The TPS-integrated digital worksheet provides a practical, technology-enhanced resource that creates a collaborative learning environment, offering a robust instructional model for mathematics educators aiming to improve higher-order cognitive competencies.

Highlights

- The TPS-integrated digital worksheet demonstrated high validity and usability across expert evaluations and student-teacher trials.
- Integrating cooperative learning principles into digital platforms significantly outperforms traditional instruction in developing mathematical connection ability.
- Collaborative digital design effectively fosters student reasoning across mathematical concepts, other disciplines, and real-life situations.

Keywords

Digital Worksheet; Educational Technology; Mathematical Connection Ability; Think-Pair-Share; Technology-Enhanced Learning

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INTRODUCTION

The rapid advancement of digital technologies has transformed educational practices worldwide, encouraging educators to integrate technology-enhanced learning environments into classroom instruction [1], [2]. Digital learning tools are increasingly utilized to promote student engagement, collaboration, and higher-order thinking skills [3], [4]. In mathematics education, technology integration is expected not only to improve students' academic achievement but also to facilitate meaningful learning experiences that enable learners to connect mathematical concepts with real-world contexts [5], [6]. Consequently, educational technology has become a crucial component in supporting effective and student-centered learning in the twenty-first century [7], [8], [9].

Despite the growing adoption of educational technologies, many mathematics classrooms continue to face challenges in developing students' higher-order cognitive skills [10], [11]. One important competency emphasized in mathematics education is mathematical connection ability, which refers to students' capacity to recognize relationships among mathematical concepts, connect mathematics with other disciplines, and apply mathematical ideas to everyday situations [12], [13]. Meaningful mathematics learning depends largely on students' ability to recognize relationships among mathematical ideas and connect them with knowledge acquired in different contexts. Such connections support conceptual understanding, improve problem-solving performance, and encourage more flexible reasoning [14], [15]. Nevertheless, research has shown that many students continue to face challenges in connecting mathematical concepts, integrating mathematics with other fields, and applying mathematical knowledge to real-world situations [16].

The challenge of fostering mathematical connections is closely related to instructional practices implemented in classrooms [17]. Traditional teacher-centered approaches often limit students' opportunities to actively construct knowledge, exchange ideas, and engage in meaningful discussions. As a result from research [18] mathematical concepts are frequently learned as isolated procedures rather than as interconnected bodies of knowledge. From a constructivist perspective, meaningful learning occurs when learners actively build knowledge through interaction, reflection, and collaboration [19]. Therefore, instructional approaches that promote active participation and social interaction are considered essential for developing deeper mathematical understanding and strengthening students' ability to establish meaningful connections among concepts [20].

Cooperative learning has been widely recognized as an effective instructional approach for enhancing student engagement and cognitive development [21]. Among various cooperative learning strategies, the Think-Pair-Share (TPS) model provides students with opportunities to individually process information, discuss ideas with peers, and share their understanding with the broader learning community [22]. Through these stages, students are encouraged to articulate their reasoning, compare perspectives, and refine their conceptual understanding. Previous studies from [23] have demonstrated that TPS can improve learning outcomes, communication skills, critical thinking, and mathematical achievement. Nevertheless, most existing studies have examined TPS implementation in conventional classroom settings, while empirical evidence regarding the integration of TPS principles into technology-enhanced learning environments remains relatively limited, particularly in relation to the development of mathematical connection ability [24].

Recent advances in educational technology have changed how learning materials are designed and used in mathematics classrooms. Unlike conventional printed worksheets, digital worksheets can integrate multimedia resources, interactive activities, collaborative tasks, and immediate feedback into a single learning platform [25], [26], [27], [28]. This integrated design creates more engaging learning experiences and enables teachers to better accommodate variations in students' learning needs and classroom participation. Previous studies from [29] have reported that digital worksheets can improve students' engagement, learning motivation, and academic performance. However, most existing research has primarily focused on product development, feasibility, usability, and general learning outcomes. Relatively little attention has been paid to how digital worksheet design can systematically facilitate higher-order mathematical competencies, particularly mathematical connection ability [30].

Similarly research from [31], a considerable body of research has investigated the effectiveness of the Think-Pair-Share (TPS) cooperative learning model in improving students' participation, communication skills, critical thinking, and mathematics achievement. These studies consistently indicate that TPS promotes active learning through individual reflection, peer discussion, and knowledge sharing. Nevertheless, most TPS-related studies have been conducted in conventional face-to-face classroom settings, while research examining the integration of TPS principles within technology-enhanced learning environments remains limited.

In parallel, mathematical connection ability has received increasing attention in mathematics education research because of its role in supporting conceptual understanding and problem-solving [32]. Previous studies from [33] have identified various instructional approaches that contribute to the development of mathematical connections, including contextual learning, problem-based learning, inquiry-based instruction, and collaborative learning. However, empirical evidence regarding the use of digital learning environments specifically designed to foster mathematical connection ability is still scarce. Furthermore, few studies have explicitly examined how technology-supported cooperative learning can facilitate students' ability to establish connections among mathematical concepts, across disciplines, and within real-life contexts.

Therefore, a significant research gap exists at the intersection of three research streams: cooperative learning through Think-Pair-Share (TPS), digital worksheet technology, and mathematical connection ability. Even though Think-Pair-Share (TPS), digital worksheets, and mathematical connection skills have all gotten plenty of attention in past research, they've almost always been treated as completely separate topics.

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When researchers look at TPS, they mostly focus on how it gets students to interact better and boosts their overall grades. On the flip side, studies on digital worksheets usually just test how user-friendly the tech is and look at broad learning results. Meanwhile, research into mathematical connections generally just evaluates different teaching styles. What's really been missing from the conversation is a closer look at how working together using digital tools for support could actually help students build and strengthen those crucial math skills.

More specifically, there remains insufficient evidence regarding how TPS principles can be embedded within a digital worksheet environment to support the development of mathematical connection ability.

To address this research gap, the present study introduces and evaluates a Think-Pair-Share (TPS)-integrated digital worksheet (E-LKPD) developed to strengthen students' mathematical connection ability in secondary mathematics classrooms. The proposed learning environment combines cooperative learning with digital technology by embedding the stages of TPS into an interactive worksheet that encourages students to establish relationships among mathematical ideas, connect mathematics with other disciplines, and apply mathematical concepts to real-world situations. Unlike previous studies that have examined digital worksheets, Think-Pair-Share (TPS), and mathematical connection ability separately, this study integrates these elements into a single instructional design. The proposed digital worksheet was not only developed as a learning resource but also evaluated through expert validation, practicality assessment, and classroom implementation to examine its effectiveness in supporting students' mathematical connection ability. By combining cooperative learning with digital technology, this study provides evidence of how instructional design can be used to promote higher-order mathematical thinking in mathematics classrooms. Based on these objectives, the study focuses on developing a TPS-integrated digital worksheet for secondary mathematics and evaluating its validity, practicality, and effectiveness in improving students' mathematical connection ability.

METHOD

A. Research Design

To create the TPS-integrated digital worksheet (E-LKPD) for this study, we relied on a Research and Development (R&D) approach. Specifically, the entire process was guided by the Four-D (4D) model introduced by Thiagarajan, Semmel, and Semmel [34], which breaks the work down into four clear stages: Define, Design, Develop, and Disseminate. We chose to go with this specific framework simply because it offers a highly organized, step-by-step roadmap for building and testing new educational materials.Following this model, the digital worksheet was designed by integrating the Think-Pair-Share (TPS) learning sequence into an online learning platform. Each learning activity was intentionally organized to encourage students to relate mathematical concepts, connect mathematics with knowledge from other disciplines, and apply their understanding to real-life situations.

B. Participants

The study was conducted at MTs Hifzil Qur'an, Indonesia. Different participants were involved during the development and evaluation stages. During the validation stage, the developed digital worksheet was evaluated by subject matter experts, instructional design experts, and educational technology experts. Following the development phase, the digital worksheet was evaluated through a series of implementation stages, including individual, small-group, and field trials involving Grade VIII students. To evaluate instructional effectiveness, the developed worksheet was implemented in two Grade VIII classes. The experimental group participated in learning activities supported by the TPS-integrated digital worksheet, whereas the control group followed conventional presentation-based instruction. With 30 students in each group, the study was able to compare learning outcomes under comparable classroom conditions.

C. Development Procedure

1.Define

The first stage of the Four-D model focused on identifying the instructional needs that would guide the development of the digital worksheet. To get a clear picture of what was actually happening during lessons, we spent time observing the classrooms, interviewing both teachers and students, and handing out surveys.

The feedback we gathered revealed something important: a large number of students were genuinely struggling to grasp mathematical connections. Seeing this challenge firsthand made it obvious that the classroom really needs digital learning materials designed to spark interaction and get students working together.

2. Design

Once we figured out exactly what the classroom needed during the Define stage, we used those insights to put together the very first prototype of the digital worksheet. The prototype focused on the topic of Relations and Functions and incorporated the Think-Pair-Share (TPS) learning sequence into each learning activity. At this stage, learning objectives, instructional materials, multimedia resources, and mathematical connection tasks were developed simultaneously using the Wizer.me platform to create an interactive learning environment.

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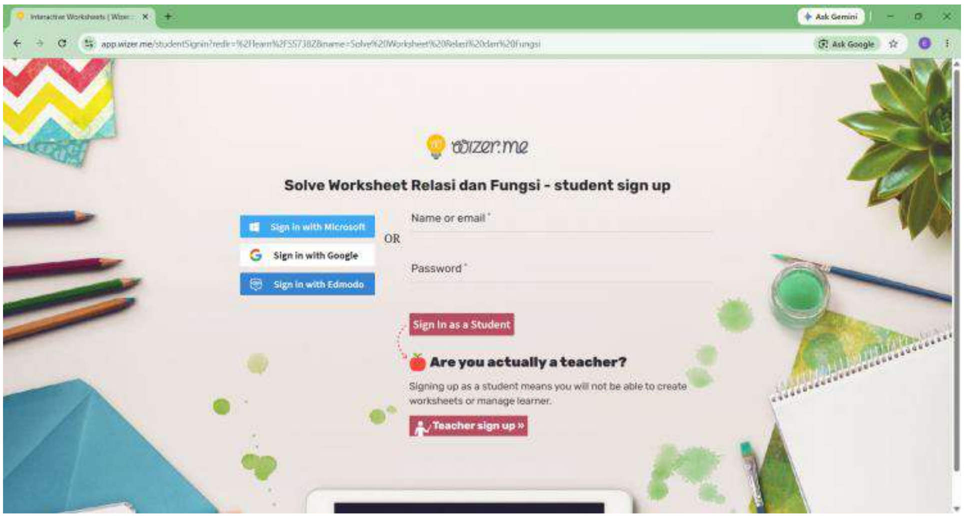
Figure 1. First Design Student Worksheet



3. Develop

During the development phase, the prototype was reviewed and validated by experts in mathematics content, instructional design, and educational media. Feedback obtained from the validation process was used to revise and improve the product. After revision, the digital worksheet was evaluated through individual trials, small-group trials, and field trials to assess its feasibility and usability.

Figure 2. *Final Design Student Worksheet*

4.Disseminate

The dissemination phase involved implementing the finalized digital worksheet in classroom learning. This phase focused on evaluating the practicality and effectiveness of the developed product through classroom application and learning outcome assessment.

D. Instruments

Several instruments were employed to collect data.

1. Validation questionnaires were used to evaluate the content quality, instructional design quality, and media quality of the developed digital worksheet.

2. Teachers and students participated in the practicality evaluation by completing questionnaires that measured the usability, accessibility, usefulness, and overall presentation quality of the digital worksheet.

3. A mathematical connection ability test was used to measure students' performance across three dimensions:

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•connections among mathematical concepts;

•connections between mathematics and other disciplines;

•connections between mathematics and real-life situations.

4. Interview and documentation protocols were used to support the needs analysis and product development process.

E. Data Analysis

The validity of the developed product was analyzed using descriptive percentage statistics based on expert evaluations and trial resultsTo figure out how practical the product actually was for everyday classroom use, we reviewed the survey feedback gathered from both the teachers and the students. Then, to see if the worksheet was truly effective, we compared the mathematical connection scores between the experimental and control groups using an independent-samples t-test.

Of course, before diving into that main comparison, we had to do a bit of statistical housekeeping. We ran normality and homogeneity tests just to make sure our data checked all the necessary boxes for this kind of analysis. Once we confirmed the numbers were good to go, we went ahead with the t-test, setting our significance level at the standard 0.05.

A statistically significant difference between the experimental and control groups indicated the effectiveness of the TPS-integrated digital worksheet in improving students' mathematical connection ability.

RESULTS AND DISCUSSION

A. Results

1. Validation of the TPS-Integrated Digital Worksheet

The first objective of this study was to develop a TPS-integrated digital worksheet that meets the criteria of validity and feasibility for mathematics learning. To evaluate the quality of the developed product, expert validation and user trials were conducted. The results are presented in Table 1.

Table 1. *Summary of Validation Results*

Evaluation Component	Percentage (%)	Category
Content Expert	97	Excellent
Instructional Design Expert	85	Excellent
Media Expert	90	Excellent
Individual Trial	88	Excellent
Small Group Trial	90	Excellent
Field Trial	89	Excellent
Overall Mean	90	Excellent

The results in Table 1 indicate that the TPS-integrated digital worksheet achieved high scores across all validation components. The overall feasibility score reached 90%, suggesting that the developed product met the expected standards for instructional quality, content accuracy, and media design. Among the evaluated components, content validation received the highest score (97%), followed by media validation (90%) and instructional design validation (85%).

2. Practicality of the TPS-Integrated Digital Worksheet

Following the validation stage, the practicality of the developed digital worksheet was evaluated through teacher and student responses during classroom implementation. The practicality assessment focused on accessibility, usefulness, and presentation quality. The results are summarized in Table 2.

Table 2. *Practicality Evaluation Results*

Respondent	Percentage (%)	Category
Teachers	88	Excellent
Students	88	Excellent

The findings presented in Table 2 show that both teachers and students evaluated the developed digital worksheet positively. The practicality score reached 88% for both respondent groups, indicating that the TPS-integrated digital worksheet was easy to use and beneficial for supporting mathematics learning activities.

3. Ability Impact of the TPS-Integrated Digital Worksheet on Students' Mathematical Connection Ability

The effectiveness of the digital worksheet was determined by analyzing students' performance in three dimensions of mathematical connection ability. The comparison between the experimental and control groups is presented in Table 3.

Table 3. *Mean Scores of Mathematical Connection Ability*

Dimension	Control Group	Experimental Group
Connections among mathematical concepts	2.73	2.97
Connections between mathematics and other disciplines	2.77	3.77

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Connections between mathematics and real-life situations	3.10	3.67

As shown in Table 3, students in the experimental group obtained higher scores across all dimensions of mathematical connection ability than students in the control group. The largest difference was observed in the dimension concerning connections between mathematics and other disciplines. To further evaluate the effectiveness of the intervention, students' post-test scores were compared between the experimental and control groups. The results are presented in Table 4.

Table 4. *Comparison of Post-Test Scores*

Group	Mean Score
Experimental Group	81.9
Control Group	63.3

Table 4 shows that students who learned using the TPS-integrated digital worksheet achieved a substantially higher mean score than students who received conventional instruction. To determine whether the observed difference was statistically significant, an independent-samples t-test was conducted. The results are shown in Table 5.

Table 5. *Independent Samples t-Test Results*

Variable	Sig. (2-tailed)
Mathematical Connection Ability	0.000

The results presented in Table 5 indicate that the significance value was below the 0.05 threshold, suggesting a statistically significant difference between the experimental and control groups. Therefore, the TPS-integrated digital worksheet was found to be effective in enhancing students' mathematical connection ability.

B. Discussion

1. Designing TPS-Integrated Digital Worksheets for Technology-Enhanced Cooperative Learning

The results demonstrated that the TPS-integrated digital worksheet achieved a high level of quality, as reflected in the overall validation score of 90%. High ratings were consistently obtained from content experts (97%), instructional design experts (85%), and media experts (90%). In addition, positive evaluations were obtained during individual, small-group, and field trials. These findings indicate that the developed digital worksheet successfully met the pedagogical, content, and technological requirements expected of a technology-enhanced learning resource.

The high validation results may be attributed to the instructional design approach adopted during development. The worksheet was not designed solely as a digital version of a conventional worksheet but as a learning environment that integrated TPS learning stages into interactive digital activities. This design enabled students to engage in individual reflection, peer discussion, and collaborative knowledge sharing while interacting with mathematical content. Such characteristics are consistent with contemporary Educational Technology perspectives emphasizing the alignment of pedagogy, content, and technology in instructional design.

The practicality findings further support the quality of the developed learning environment. Both teachers and students reported identical practicality scores of 88%, indicating that the digital worksheet was perceived as accessible, useful, and easy to implement in classroom learning. These findings suggest that the integration of TPS learning activities within the Wizer.me platform did not create additional instructional complexity but instead supported learning implementation in a manageable manner.

The findings are consistent with previous studies from [28] reporting that digital worksheets can improve learning accessibility, engagement, and instructional effectiveness. However, unlike many existing studies that primarily evaluate technical usability, the present study demonstrates that digital worksheets can also function as collaborative learning environments when supported by appropriate pedagogical structures. Therefore, the contribution of this study lies not only in the development of a digital worksheet but also in demonstrating how cooperative learning principles can be embedded within educational technology to support meaningful learning experiences.

2. Enhancing Mathematical Connection Ability through TPS Learning Processes

The most important finding of this study concerns the effectiveness of the TPS-integrated digital worksheet in enhancing students' mathematical connection ability. Students in the experimental group achieved a substantially higher post-test mean score (81.9) than those in the control group (63.3). Furthermore, the independent-samples t-test revealed a statistically significant difference between the two groups ($p = 0.000$). These findings indicate that the developed learning environment contributed positively to students' ability to establish mathematical connections.

The results show that students who used the TPS-integrated digital worksheet demonstrated better performance across all dimensions of mathematical connection ability than those in the control group. The greatest improvement was found in the ability to connect mathematics with other disciplines, where the experimental group achieved a mean score of 3.77 compared with 2.77 for the control group. This finding suggests that integrating cooperative learning into a digital learning environment created more opportunities for students to relate mathematical concepts to knowledge beyond mathematics.

One possible explanation lies in the way the worksheet incorporated the Think-Pair-Share learning process. To start off, the students tackled the math problems on their own. Once they had some time to think things through, they teamed up with their classmates to bounce ideas off each other before the whole class came together to hash out the details.

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Instead of just mindlessly rushing through a worksheet, the students really got involved. They compared how they approached the problem, defended their logic, and were totally open to changing their original answers when a classmate made a good point. All of this back-and-forth teamwork clearly paid off. It helped them grasp the core concepts on a much deeper level, making it far easier for them to connect different math topics together and even see how they apply to other subject areas.

We can also make sense of these results by looking at them through the lens of constructivist and social constructivist theories. Essentially, the constructivist approach suggests that learning happens when students actively connect what they already know with new experiences. Social constructivism takes that idea a step further, highlighting just how important conversation and teamwork are when building that knowledge.

Because the Think-Pair-Share method was built right into the digital worksheet, it gave students the best of both worlds. They had the space to process the information and figure things out on their own, while also working together to deepen their overall understanding as a team.

. Consequently, students were able to establish stronger relationships among mathematical concepts and connect mathematical knowledge to broader disciplinary and real-life contexts.

The present findings support previous studies from [24] demonstrating the positive influence of TPS on conceptual understanding, reasoning ability, and active learning participation. Studies on contextual learning and collaborative problem-solving consistently report positive effects on students' mathematical connection ability because both approaches encourage learners to develop a deeper understanding of mathematical concepts. However, these instructional strategies have generally been examined independently rather than integrated within a single learning design. In the present study, Think-Pair-Share (TPS) was embedded into a digital worksheet to combine these complementary principles in one technology-supported learning environment, providing a practical approach to strengthening students' mathematical connection ability.

3. Contribution to Educational Technology Research

Beyond its impact on mathematics learning, this study contributes to the broader Educational Technology literature. The findings demonstrate that digital worksheets can serve purposes beyond content delivery and assessment. When combined with appropriate pedagogical strategies, digital worksheets can become environments that support interaction, collaboration, and higher-order cognitive development.

The present findings highlight the potential of integrating Think-Pair-Share (TPS), digital worksheets, and mathematical connection ability within a single technology-supported instructional design. While past research has usually treated these areas as completely separate topics, this new setup actually weaves them together into one unified teaching approach. The jump in student performance we saw really drives home an important point: digital tools do a lot more for students when they are purposefully paired with group work. Ultimately, technology is far more effective when it is used to spark collaboration, rather than just acting as a fancy screen for handing out information.

Looking at the bigger picture, these findings really highlight just how much instructional design matters when we talk about educational technology. The reason this TPS-integrated digital worksheet worked so well wasn't just because it had flashy digital features. Instead, its real success came from how teamwork and collaboration were baked right into every single step of the lesson. Because of this setup, students didn't just sit back they actively jumped in, bounced ideas off one another, and truly wrapped their heads around the math by engaging with both the tech and their classmates. For teachers and instructional designers looking to build tech-driven classrooms that genuinely push students to think critically and connect deeply with the material, these results offer a really practical roadmap.

CONCLUSION

This study aimed to develop and evaluate a TPS-integrated digital worksheet (E-LKPD) to enhance students’ mathematical connection ability in secondary mathematics education. The findings demonstrated that the developed digital worksheet achieved high levels of validity and practicality, indicating that it met the pedagogical, technological, and instructional requirements necessary for classroom implementation. The positive evaluations provided by experts, teachers, and students suggest that the integration of Think-Pair-Share (TPS) learning stages within a digital learning environment resulted in a feasible and user-friendly instructional resource.

The study also highlighted just how much the TPS-integrated digital worksheet boosted the students' ability to make mathematical connections. Those who learned with this new setup consistently outperformed the students in traditional classes. We saw this growth across the board whether they were linking different math concepts together, bridging math with other school subjects, or tying it to everyday life.

The biggest leap we noticed was in how well they could connect math to other disciplines. This likely comes down to the collaborative elements baked right into the worksheet. By naturally pushing the students to talk things out, compare their perspectives, and apply math ideas across different scenarios, the teamwork aspect really helped everything click into place.

Ultimately, what these findings show is that digital learning tools don't succeed just because they use great technology. Their real impact comes down to how thoughtfully strong teaching methods are woven right into their overall design.The TPS-integrated digital worksheet developed in this study illustrates how cooperative learning processes can be incorporated into a digital environment to support individual reflection, collaborative discussion, and shared knowledge construction. Together, these learning experiences contribute to the development of higher-order mathematical thinking.

From an Educational Technology perspective, this study contributes to the literature by providing empirical evidence that cooperative learning principles can be successfully operationalized within digital worksheet environments to support mathematical connection development. The proposed TPS-integrated digital worksheet offers a practical instructional design model that combines technology-enhanced learning, collaborative learning, and mathematical cognition. Therefore, the study highlights the potential of pedagogically driven digital learning environments to foster meaningful learning experiences and improve students' higher-order cognitive outcomes.

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