

PEER COLLABORATION IN VIRTUAL LEARNING AND ITS IMPACT ON HIGH SCHOOL STUDENTS' MATHEMATICAL UNDERSTANDING

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ABSTRACT. The transition from face-to-face instruction to online learning requires students to collaborate effectively with peers, particularly in understanding abstract mathematical concepts. Peer collaboration plays an important role in maintaining academic interaction, social support, and communication effectiveness in virtual learning environments. This study aims to describe the level of peer collaboration in online learning based on four indicators—interaction, individual responsibility, social support, and communication effectiveness—and to analyze students' mathematical understanding in terms of problem solving, communication, connections, representation, and reasoning. This study employed a mixed methods approach with an embedded concurrent design. The participants consisted of 32 students who completed a peer collaboration questionnaire, 5 students who took a mathematical understanding test, and 3 students who participated in semi-structured interviews. Research instruments included a five-point Likert-scale questionnaire, open-ended mathematical understanding test items, and an interview guideline. Quantitative data were analyzed descriptively, while qualitative data were examined using thematic analysis to support and deepen the quantitative findings. The results indicate that peer collaboration in virtual learning is at a moderate-to-high level, with social support as the strongest aspect, whereas online interaction is the weakest. Students' mathematical understanding is categorized as moderate, showing high performance in problem solving, communication, and connections, but low performance in representation and reasoning. Interview findings reveal that low responsiveness among group members is a major obstacle to effective online collaboration. These findings suggest the need for more interactive collaborative designs and enhanced representational support to optimize students' mathematical understanding in virtual learning contexts.

Keywords: peer collaboration, virtual learning, mathematical understanding, high school students

ABSTRAK. Transisi dari pembelajaran tatap muka ke pembelajaran daring mengharuskan siswa untuk berkolaborasi secara efektif dengan teman sebaya, khususnya dalam memahami konsep matematika abstrak. Kolaborasi antar teman sebaya memainkan peran penting dalam menjaga interaksi akademik, dukungan sosial, dan efektivitas komunikasi dalam lingkungan pembelajaran virtual. Studi ini bertujuan untuk mendeskripsikan tingkat kolaborasi antar teman sebaya dalam pembelajaran daring berdasarkan empat indikator—interaksi, tanggung jawab individu, dukungan sosial, dan efektivitas komunikasi—dan untuk menganalisis pemahaman matematika siswa dalam hal pemecahan masalah, komunikasi, koneksi, representasi, dan penalaran. Studi ini menggunakan pendekatan metode campuran dengan desain konkuren terintegrasi. Partisipan terdiri dari 32 siswa yang mengisi kuesioner kolaborasi antar teman sebaya, 5 siswa yang mengikuti tes pemahaman matematika, dan 3 siswa yang berpartisipasi dalam wawancara semi-terstruktur. Instrumen penelitian meliputi kuesioner skala Likert lima

poin, item tes pemahaman matematika terbuka, dan panduan wawancara. Data kuantitatif dianalisis secara deskriptif, sedangkan data kualitatif diperiksa menggunakan analisis tematik untuk mendukung dan memperdalam temuan kuantitatif. Hasil penelitian menunjukkan bahwa kolaborasi antar teman sebaya dalam pembelajaran virtual berada pada tingkat sedang hingga tinggi, dengan dukungan sosial sebagai aspek terkuat, sedangkan interaksi daring merupakan aspek terlemah. Pemahaman matematika siswa dikategorikan sebagai sedang, menunjukkan kinerja tinggi dalam pemecahan masalah, komunikasi, dan koneksi, tetapi kinerja rendah dalam representasi dan penalaran. Temuan wawancara mengungkapkan bahwa rendahnya responsivitas di antara anggota kelompok merupakan hambatan utama bagi kolaborasi daring yang efektif. Temuan ini menunjukkan perlunya desain kolaborasi yang lebih interaktif dan dukungan representasional yang lebih baik untuk mengoptimalkan pemahaman matematika siswa dalam konteks pembelajaran virtual.

Kata Kunci: Kolaborasi antar teman sebaya, pembelajaran virtual, pemahaman matematika, siswa sekolah menengah atas

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1. INTRODUCTION

Mathematical understanding is a central goal of mathematics education, as it enables students to reason logically, communicate mathematical ideas, establish conceptual connections, and represent abstract concepts meaningfully (Karadag, 2010; Moreno et al., 2025). Learning mathematics is therefore not limited to procedural fluency, but involves deeper cognitive processes that support problem solving and reasoning. However, achieving such understanding remains a major challenge in secondary education, particularly when students encounter abstract mathematical concepts that require explanation, discussion, and conceptual justification.

In recent years, this challenge has become more pronounced due to the rapid transition from face-to-face instruction to virtual learning environments. Although online learning provides flexibility and access to digital resources, it often reduces direct interaction among students, which is essential for constructing mathematical meaning (Jojo, 2022; Karadag, 2010; Merchant et al., 2014; Sukestiyarno, 2025). Limited peer discussion, delayed feedback, and uneven participation frequently characterize online mathematics classrooms, potentially hindering students' opportunities to clarify misconceptions and develop higher-order thinking skills. These conditions highlight an urgent need to identify instructional strategies that can sustain meaningful interaction and support mathematical understanding in virtual learning contexts.

One approach that has gained increasing attention is peer collaboration. Peer collaboration emphasizes student interaction through shared problem solving, explanation of ideas, and mutual support during the learning process (Chu et al., 2018; Johnston et al., 2014; Song et al., 2024). From a theoretical perspective, collaborative learning aligns with social constructivist views, which posit that knowledge is constructed through social interaction and dialogue. Through collaboration, students can articulate their thinking, receive immediate feedback, and refine their understanding by engaging with diverse perspectives. In mathematics learning, such interaction is particularly important because meaning is often negotiated through explanation, argumentation, and representation.

Previous studies have demonstrated that peer collaboration can positively influence students' learning outcomes, engagement, and motivation. Research in mathematics education has shown that collaborative learning environments encourage active participation and improve students' ability to communicate mathematical ideas and solve problems. In online settings, collaborative activities supported by digital platforms have been found to enhance student interaction and participation when compared to individual learning approaches. These findings suggest that peer collaboration has the potential to mitigate some limitations of virtual learning by fostering academic and social interaction (Johnston et al., 2014; Ugo & Oliweh, 2024; Zhang & Hwang, 2023).

However, existing studies largely focus on general academic achievement, participation rates, or engagement levels, rather than examining how peer collaboration supports specific components of mathematical understanding. Many studies treat mathematical understanding as a single outcome variable, without distinguishing between its key dimensions such as problem solving, representation, reasoning, communication, and connections. As a result, there is limited empirical evidence explaining which aspects of mathematical understanding are effectively

supported through peer collaboration in online learning environments.

Furthermore, research that integrates students' perceptions of peer collaboration with direct assessments of mathematical understanding remains scarce, particularly at the secondary school level. Most studies rely on survey data or test scores alone, without exploring students' collaborative experiences in depth (Chan et al., 2023; Dhakal, 2022; Moyer-Packenham & Westenskow, 2013; Woolf, 2010). This gap is especially evident in contexts where virtual learning is implemented under constraints such as varying levels of technological access and inconsistent student responsiveness, which may shape unique patterns of collaboration and learning.

Based on these gaps, this study offers a novel contribution by integrating an analysis of peer collaboration dimensions interaction, individual responsibility, social support, and communication effectiveness with an in-depth examination of students' mathematical understanding across five indicators: problem solving, communication, connections, representation, and reasoning. Unlike previous studies that emphasize outcomes in isolation, this research combines quantitative and qualitative data to capture both the level of collaboration and the underlying dynamics experienced by students during virtual learning.

Therefore, this study aims to investigate the role of peer collaboration in virtual learning and its influence on high school students' mathematical understanding. By examining how collaborative processes relate to specific dimensions of mathematical understanding, this study seeks to provide empirical insights that can inform the design of more effective and responsive online mathematics learning environments.

2. RESEARCH METHOD

2.1 Type of Research

This study employed a mixed methods approach with an embedded concurrent design, in which quantitative and qualitative data were collected simultaneously, with quantitative data serving as the primary strand. This approach was chosen to obtain a comprehensive understanding of peer collaboration in virtual learning and its influence on students' mathematical understanding by integrating numerical trends with in-depth qualitative insights.

2.2 Time and Place of the Study

The study was conducted during the second semester of the 2024/2025 academic year at a public Islamic senior high school (Madrasah Aliyah Negeri) located in Makassar, Indonesia. At the time of the study, mathematics instruction was implemented through virtual learning using Google Classroom and Google Meet.

2.3 Research Objective

The objective of this study was to examine the role of peer collaboration in virtual learning and its influence on high school students' mathematical understanding. Specifically, the study aimed to (1) describe the level of peer collaboration based on interaction, individual responsibility, social support, and communication effectiveness, and (2) analyze students' mathematical understanding in terms of problem solving, communication, connections, representation, and reasoning.

2.4 Research Subjects

The research subjects consisted of Grade XII students who had participated in online mathematics learning. A total of 32 students were involved as respondents for the peer collaboration questionnaire. From this group, 5 students were selected to complete a mathematical understanding test, and 3 students participated in semi-structured interviews. Participants were selected using purposive sampling based on the following criteria: (1) active participation in virtual mathematics learning, (2) basic proficiency in using digital learning platforms, and (3) willingness to participate in collaborative learning activities and research data collection.

2.5 Research Procedures

The research procedures consisted of several stages. First, the researcher prepared and validated the research instruments, including the questionnaire, test items, and interview guidelines. Second, the peer collaboration questionnaire was administered to all participants through an online platform. Third, selected students completed the mathematical understanding test to obtain descriptive data on their conceptual understanding. Fourth, semi-structured interviews were conducted online to explore students' experiences and perceptions of peer collaboration during virtual learning. Finally, all collected data were organized and analyzed according to the selected analysis techniques.

2.6 Research Instruments

Three instruments were used in this study.

1. Peer Collaboration Questionnaire, consisting of 20 items measured on a five-point Likert scale, designed to assess interaction, individual responsibility, social support, and communication effectiveness.
2. Mathematical Understanding Test, comprising five open-ended questions developed based on indicators proposed by the National Council of Teachers of Mathematics, including problem solving, reasoning, communication, connections, and representation.
3. Semi-Structured Interview Guide, used to explore students' experiences, interaction patterns, and perceived challenges in online peer collaboration.

2.7 Data Analysis Techniques

Quantitative data from the questionnaire and test were analyzed using descriptive statistical techniques, including mean scores, standard deviations, frequency distributions, and categorization of results. Inferential statistical analysis was not conducted because the study did not involve experimental treatment or pre-post comparison. Qualitative data obtained from interviews were analyzed using thematic analysis, which involved transcription, open coding, categorization, and theme identification. Methodological triangulation was applied by comparing quantitative and qualitative findings to enhance the credibility and validity of the results.

2.8 Ethical Consideration

This study adhered to ethical research principles. Informed consent was obtained from all participants prior to data collection. Participants' identities were kept confidential, and all data were used solely for research purposes. Digital privacy and data security were maintained throughout the research process.

3. RESULT AND DISCUSSION

3.1 Research Results

Peer Collaboration in Virtual Learning

Peer collaboration was measured using a questionnaire completed by 32 students, consisting of four indicators: interaction, individual responsibility, social support, and communication effectiveness. The results indicate that overall peer collaboration in virtual learning was categorized as moderate to high ($M = 71.91$; $SD = 10.41$). Among the four indicators, social support achieved the highest mean score ($M = 20.13$; $SD = 3.21$), suggesting that students perceived substantial emotional encouragement, academic assistance, and cooperative behavior from their peers during online learning. This finding reflects a relatively strong sense of peer support despite the limitations of virtual interaction.

In contrast, interaction obtained the lowest mean score ($M = 16.09$; $SD = 3.49$), indicating that direct communication and active discussion among students during online collaboration were not yet optimal. Students' participation in discussions, responsiveness to peers' messages, and willingness to express opinions were reported at a moderate level. The indicators of individual responsibility ($M = 17.88$; $SD = 3.16$) and communication effectiveness ($M = 17.81$; $SD = 3.24$) were also categorized as moderate, suggesting that while students generally completed their tasks and were able to convey ideas, the quality and intensity of collaborative interaction varied across groups.

Students' Mathematical Understanding

Students' mathematical understanding was assessed through an open-ended test administered to five selected students. The test evaluated five indicators: problem solving, communication, connections, representation, and reasoning. The descriptive results are illustrated in Figure 1.

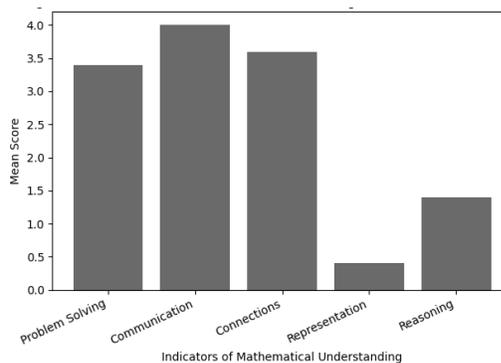


Figure 1. Students' Mathematical Understanding based on NCTM Indicators

The results show that students demonstrated high achievement in communication ($M = 4.00$), connections ($M = 3.60$), and problem solving ($M = 3.40$). These findings indicate that students were generally able to explain mathematical ideas verbally, relate mathematical concepts to real-life situations, and apply appropriate procedures to solve contextual problems.

However, students' performance was notably low in representation ($M = 0.40$) and reasoning ($M = 1.40$). Many students experienced difficulty in translating mathematical ideas into appropriate representations, such as diagrams, symbols, or verbal explanations. In addition, students' reasoning tended to focus on procedural steps rather than providing logical justification or conceptual explanations for their solutions. Overall, the total score of mathematical understanding was categorized as moderate ($M = 12.80$), indicating uneven development across

the assessed indicators.

Results of Semi-Structured Interviews

Semi-structured interviews conducted with three students yielded four main themes related to their experiences with peer collaboration in virtual learning.

First, interaction barriers due to low peer responsiveness were frequently reported. Students stated that online group discussions were often ineffective because some group members responded slowly or did not respond at all, which disrupted the flow of discussion and limited collaborative problem solving. Second, individual responsibility remained high. Despite limited interaction, students reported completing group tasks independently when collaboration did not function effectively. In cases of difficulty, students tended to seek assistance directly from the teacher rather than relying on peers.

Third, social support was present but inconsistent. Students acknowledged receiving help and encouragement from peers, particularly when facing difficult mathematical topics. However, this support was not consistently available due to factors such as unstable internet connections, lack of readiness, and reduced attention during online learning. Fourth, students expressed expectations for improved online collaboration, including more active and responsive group members, clearer explanations of mathematical material, and more stable technical conditions to support effective collaborative learning.

Overall, the results indicate that peer collaboration in virtual learning was implemented at a moderate to high level, with social support emerging as the most prominent aspect perceived by students. Nevertheless, limited interaction and uneven responsiveness remained significant challenges. Students' mathematical understanding was categorized as moderate, showing strengths in communication, connections, and problem solving, but weaknesses in representation and reasoning. The interview findings confirmed the quantitative results, particularly regarding interaction barriers and the inconsistent nature of peer support. Collectively, these findings suggest that while peer collaboration in virtual learning has been established, further improvement is needed to enhance its effectiveness in supporting comprehensive mathematical understanding.

3.2 Discussion

The findings of this study indicate that peer collaboration in virtual learning is moderate to high, with social support as the most dominant aspect. This is interesting. It means that even though physical space is lost, the affective dimension is not completely destroyed. Students still provide encouragement, assistance, and emotional reinforcement to one another. From a social constructivist perspective, this aligns with the idea that learning is a social process involving meaningful interactions and psychological support. Social support can function as a "cognitive buffer" that helps students persist in the face of abstract mathematical material (Chu et al., 2018; Larrain et al., 2019).

However, online interaction is actually the weakest aspect. This is a small paradox worth pondering: students feel supported, but discussions are not optimal. Theoretically, effective collaboration requires two-way dialogue, argumentation, and negotiation of meaning. Low responsiveness and disjointed discussions reduce opportunities for cognitive elaboration—the process by which students broaden and deepen their understanding through explanations to others. Without elaboration, collaboration risks devolving into administrative tasks, rather than co-construction of knowledge.

This situation helps explain the findings on mathematical understanding. Students performed highly in communication, connection, and problem-solving, but poorly in representation and

reasoning. Communication and connection may develop because students are accustomed to explaining answers verbally or linking concepts to contextual situations. However, representation and reasoning require more in-depth, argumentative, and reflective discussion. Representation demands the ability to transform ideas into various forms of symbolic, visual, or verbal – while reasoning requires explicit logical justification. Both of these abilities rely heavily on intense and responsive interaction.

These findings indicate that the presence of collaboration alone does not automatically guarantee the development of all dimensions of mathematical understanding. The quality of interaction is a key factor. Collaboration that focuses solely on task completion without exploring representation and justification tends to produce procedural, rather than conceptual, understanding.

Interview results support this interpretation. The low responsiveness of group members and the tendency for students to complete tasks independently indicate that group regulation mechanisms have not yet developed optimally. In a virtual environment, the structure and design of collaboration play a greater role than in face-to-face learning. Without explicit design – for example, role allocation, representation-based tasks, or reasoning-prompting questions – discussions can easily become disoriented.

The pedagogical implications of these findings are quite clear. Teachers need to design collaborative activities that not only require a final answer but also explore thinking processes. Tasks that require students to create diagrams, explain the reasoning behind each step, or compare two solution strategies can strengthen representation and reasoning. Furthermore, the use of interactive features such as breakout rooms with structured questioning can improve the quality of online interactions.

Theoretically, this study extends the study of collaboration in mathematics learning by demonstrating that its impact is differential on various indicators of understanding. Not all aspects of understanding develop equally. Effective collaboration needs to be explicitly linked to specific cognitive goals. This study is limited by the relatively small number of test and interview participants, so generalization of the findings requires caution. Further studies with correlational or experimental designs could test the causal relationship between collaboration quality and each indicator of mathematical understanding.

4. CONCLUSION

This study shows that peer collaboration in virtual learning is moderate to high, with social support being the most prominent aspect. Students perceived academic assistance and emotional support from their groupmates, although the quality of online interactions was not optimal. Low responsiveness and limited two-way discussions were the main obstacles affecting the effectiveness of collaboration.

Students' mathematical understanding was generally moderate, with uneven development patterns. Students demonstrated good achievement in indicators of communication, connection, and problem-solving. Conversely, indicators of representation and reasoning remained weak. These findings indicate that collaboration does not automatically guarantee the development of all dimensions of mathematical understanding. The quality of interaction and collaborative task design play a crucial role in encouraging exploration of representations and logical argumentation. This study confirms that collaboration in virtual learning needs to be designed in a more structured and interactive manner to support comprehensive mathematical understanding. Collaborative activities that emphasize concept elaboration, justification of solution steps, and the use of various forms of representation have the potential to strengthen students' reasoning skills. These findings provide an empirical contribution to the development

of collaboration-based mathematics learning designs that are more responsive to students' cognitive needs in virtual environments.

REFERENCES

- Chan, C. L., Shroff, R. H., Tsang, W. K., & ... (2023). Assessing the effects of a collaborative problem-based learning and peer assessment method on junior secondary students' learning approaches in mathematics *... of Mobile Learning ...* <https://doi.org/10.1504/IJMLO.2023.128342>
- Chu, H. C., Chen, J. M., & Tsai, C. L. (2018). Effects of an online formative peer-tutoring approach on students' learning behaviors, performance and cognitive load in mathematics. *Learning Analytics*. <https://doi.org/10.4324/9780429428500-6>
- Dhakal, P. K. (2022). Learning Mathematics through virtual mode: A review of literature. *Siddhajyoti Interdisciplinary Journal*. <https://nepjol.info/index.php/sij/article/view/46278>
- Johnston, S. C., Greer, D., & Smith, S. J. (2014). Peer learning in virtual schools. ... *of E-Learning & Distance Education ...* <https://www.ijede.ca/index.php/jde/article/view/853>
- Jojo, Z. (2022). Engaging mathematics student-teachers in an Open Distance e-Learning context. *Perspectives in Education*. <https://doi.org/10.18820/2519593X/pie.v40.i1.12>
- Karadag, Z. (2010). *Analyzing students' mathematical thinking in technology-supported environments*. utoronto.scholaris.ca. <https://utoronto.scholaris.ca/items/64fc5a65-41c0-47f6-ad29-5e21e5c02a77>
- Larrain, A., Freire, P., López, P., & Grau, V. (2019). Counter-arguing during curriculum-supported peer interaction facilitates middle-school students' science content knowledge. *Cognition and Instruction*. <https://doi.org/10.1080/07370008.2019.1627360>
- Merchant, Z., Goetz, E. T., Cifuentes, L., & ... (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. ... *& Education*. <https://www.sciencedirect.com/science/article/pii/S0360131513002108>
- Moreno, Z. S., Bahameish, M., & ... (2025). Gamifying Arabic Mathematics Education: The Impact of Digital Learning on Student Performance and Motivation. ... *Engineering Education ...* <https://ieeexplore.ieee.org/abstract/document/11016515/>
- Moyer-Packenham, P. S., & Westenskow, A. (2013). Effects of virtual manipulatives on student achievement and mathematics learning. ... *and Personal Learning ...* <https://www.igi-global.com/article/effects-of-virtual-manipulatives-on-student-achievement-and-mathematics-learning/95162>
- Song, Y., Kim, J., Liu, Z., Li, C., & Xing, W. (2024). Students' perceived roles, opportunities, and challenges of a generative AI-powered teachable agent: a case of middle school math class. ... *on Technology in Education*. <https://doi.org/10.1080/15391523.2024.2447727>
- Sukestiyarno, Y. L. (2025). Problem-Based Learning Based on Electronic Module: Students' Mathematical Communication Process in Terms of Cognitive Style. *Educational Process: International Journal*. <https://eric.ed.gov/?id=EJ1483386>
- Ugo, H. E., & Oliweh, S. I. (2024). Overview of the Impacts of Inquiry-Based and Peer Teaching Strategies on Mathematics Achievement. ... *Applied Sciences Journal of Mathematical ...* <https://fnasjournals.com/index.php/FNAS-JMNS/article/view/539>
- Woolf, B. P. (2010). *Building intelligent interactive tutors: Student-centered strategies for revolutionizing e-learning*. books.google.com. https://books.google.com/books?hl=en&lr=&id=MnrUj3J_VuEC&oi=fnd&pg=PP1

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%27+mathematical+understanding&ots=lzyXf6gv0k&sig=MW4gCSXszYUPmiba5iJC
ap0BDU8

Zhang, D., & Hwang, G. J. (2023). Effects of interaction between peer assessment and problem-solving tendencies on students' learning achievements and collaboration in mobile technology *Journal of Educational Computing*
<https://doi.org/10.1177/07356331221094250>