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Online Collaborative Learning among University Students in Mathematics Education during COVID-19

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التعلم التعاوني عبر الإنترنت بين طلاب الجامعات في تعليم الرياضيات خلال جائحة كوفيد-19

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Abstract:
The COVID-19 pandemic necessitated a sudden shift from face-to-face to online learning, significantly transforming the educational landscape, particularly in mathematics education, where collaboration and discourse are central to deep understanding. This study explores the experiences of university students in mathematics education as they engaged in online collaborative learning during the lockdown period. Utilizing a qualitative case study approach, data were collected through semi-structured interviews, online observation logs, and collaborative task artifacts involving third-year mathematics education majors. Thematic analysis revealed four key findings: the strategic use of digital platforms (e.g., Zoom, Google Docs, GeoGebra), the evolving nature of peer collaboration in virtual settings, the challenges related to digital access, engagement, and coordination, and the perceived benefits of flexibility, independence, and exposure to diverse problem-solving strategies. The results support theoretical models such as the Community of Inquiry and Vygotsky's sociocultural theory, illustrating that meaningful collaboration and cognitive development are achievable in well-structured digital environments. The study offers practical recommendations for educators and institutions to design inclusive, interactive, and pedagogically sound online collaborative experiences in mathematics. It concludes with implications for future hybrid education and suggestions for continued research into digital mathematics learning.

Keywords: Online Collaborative Learning, Mathematics Education, COVID-19 Lockdown, Digital Pedagogy, Higher Education.

الملخص
فرضت جائحة كوفيد-19 انتقالاً مفاجئًا من التعليم الوجاهي إلى التعليم الإلكتروني، مما أدى إلى تحوّل كبير في المشهد التعليمي، لا سيما في تعليم الرياضيات، حيث تُعدّ التعاون والمناقشة من العناصر الأساسية للفهم العميق. تستكشف هذه الدراسة تجارب طلاب الجامعات المتخصصين في تعليم الرياضيات أثناء مشاركتهم في التعلم التعاوني عبر الإنترنت خلال فترة الإغلاق. استخدمت الدراسة منهج دراسة الحالة النوعية، وجُمعت البيانات من خلال مقابلات شبه منظمة، وسجلات ملاحظات عبر الإنترنت، ونتاجات لمهام تعاونية، شملت طلاب السنة الثالثة في برنامج تعليم الرياضيات. كشفت التحليلات الموضوعية عن أربعة محاور رئيسية: الاستخدام الاستراتيجي للمنصات الرقمية (مثل Zoom و Google Docs وGeoGebra)، وتطور طبيعة التعاون بين الأقران في البيئات الافتراضية، والتحديات المرتبطة بالوصول الرقمي

والمشاركة والتنسيق، والفوائد المتصورة مثل المرونة والاستقلالية والانفتاح على استراتيجيات متنوعة في حل المشكلات. تدعم النتائج نماذج نظرية مثل نموذج مجتمع الاستقصاء (Community of Inquiry) ونظرية فيغوتسكي الاجتماعية الثقافية، حيث تُظهر أن التعاون الفعّال والتطور المعرفي ممكنان في بيئات رقمية مُعدة بشكل جيد. تقدم الدراسة توصيات عملية للمعلمين والمؤسسات لتصميم تجارب تعلّم تعاونية عبر الإنترنت تكون شاملة وتفاعلية ومرتكزة على أسس تربوية، وتختتم بدلالات لمستقبل التعليم المدمج ومقترحات لأبحاث مستقبلية في مجال تعليم الرياضيات الرقمي.

الكلمات المفتاحية: التعلم التعاوني عبر الإنترنت، تعليم الرياضيات، إغلاق كوفيد-19، التربية الرقمية، التعليم العالي.

Introduction

The global COVID-19 crisis led to widespread lockdowns that disrupted educational systems at all levels, including pre-school, school, and tertiary institutions. In the context of tertiary education, defined as post-secondary study such as university learning, these lockdowns necessitated an abrupt transition from traditional face-to-face instruction to online learning modalities [1,2]. This rapid shift presented significant challenges for many university students, particularly in terms of collaborative learning. Confinement to a single domestic space, often shared with family members, partners, or roommates, introduced new responsibilities and distractions that interfered with students' ability to engage effectively in academic collaboration. These changes had broader implications for students' overall well-being. As teaching and learning moved online worldwide, both educators and students were required to adapt swiftly to new forms of critical and creative engagement via digital platforms [3,4].

The urgency of the transition not only compelled instructors to embrace eLearning technologies but also required students and their families to rely heavily on digital tools to meet educational, professional, and personal objectives [5,6]. Given the ongoing nature of the pandemic and the potential recurrence of lockdown measures, it is essential to examine the impact of these disruptions on students' learning experiences. Understanding both the challenges and opportunities associated with eLearning under lockdown conditions can inform future strategies, particularly as digital elements become increasingly integrated into tertiary education delivery [7,8].

The teaching and learning of mathematics, particularly during times of crisis, necessitate pedagogically sound and technologically integrated approaches. The COVID-19 pandemic underscored the critical need for effective instructional designs capable of supporting online mathematics education. However, this abrupt and unprecedented shift to digital learning environments also brought to the forefront several longstanding challenges [9,10]. These include the transformation of teacher, student interactions, the facilitation of student collaboration, the complex interplay between technology and mathematical content, and the digital competencies required of educators [11,12]. Central to these challenges is a fundamental pedagogical question: how can digital tools and technologies effectively support the development of mathematical understanding and knowledge?.

Despite these concerns, the mathematics education community responded swiftly by proposing innovative didactic strategies and integrating a range of digital teaching and learning solutions. During the COVID-19 lockdown, educators revisited and expanded the didactic use of video conferencing, screen recording, and online collaboration tools, such as Zoom, to maintain instructional continuity. Teachers who embraced these tools reported novel and promising outcomes for mathematics instruction, particularly in fostering engagement and supporting conceptual understanding [13,14]. Several studies have examined online collaborative learning among university students in mathematics education during the COVID-19 pandemic. The study [15] investigated self-regulated learning (SRL) profiles among middle school students and their relationship with classroom engagement and mathematics achievement. Using motivational, regulatory, and contextual factors, a cluster analysis identified four distinct student profiles based on levels of SRL and perceived support. Students with high SRL and strong perceived support demonstrated the most favorable outcomes, including higher engagement and math achievement. In contrast, the least adaptive group, characterized by low SRL and weak school connection, showed significantly lower math scores. The study highlights the critical role of SRL and contextual support in academic success and suggests directions for future research.

This study [16] investigated the impact of online learning on students' motivation, self-efficacy, and anxiety in mathematics during the "New Normal" in Philippine education. Utilizing a quasi-experimental one-group pre-post-test design, the researchers administered adapted questionnaires to assess changes in students' psychological responses over a six-week period of synchronous online instruction. The findings revealed significant declines in both mathematics motivation and self-efficacy, while anxiety levels remained consistently high. Contributing factors to students' difficulties included poor

internet connectivity, low motivation for self-directed learning, and increased household responsibilities. The study underscores the urgent need to enhance online learning delivery, improve internet infrastructure, and implement engaging and supportive instructional strategies in mathematics to foster motivation and reduce student anxiety.

This correlational study [17] investigated the relationship between mathematics self-efficacy and mathematics performance in an online learning environment during the COVID-19 pandemic. Conducted among 75 university students in Mataram, the research focused on self-efficacy scores and performance in trigonometry. Using a self-efficacy questionnaire and performance scores, the study found that most students reported high levels of mathematical self-efficacy. Statistical analysis revealed a positive correlation between self-efficacy and mathematics performance, with self-efficacy accounting for 14.8% of the variation in students' performance. The findings suggest that enhancing students' self-efficacy may contribute to improved mathematical achievement in online settings.

This study contributes significantly to the growing body of research on digital pedagogy in mathematics education by offering empirical insights into how university students experienced collaborative learning during the COVID-19-induced shift to online instruction. By employing a qualitative case study approach, the research highlights how digital platforms such as Zoom, Google Docs, and GeoGebra were strategically utilized to sustain mathematical collaboration and discourse in virtual environments. The study identifies both the challenges, such as limited digital access, reduced engagement, and coordination difficulties, and the benefits of online collaboration, including enhanced flexibility, autonomy, and exposure to diverse problem-solving strategies. The findings affirm the relevance of theoretical models such as the Community of Inquiry and Vygotsky's sociocultural theory in the context of remote learning, demonstrating that meaningful cognitive and social engagement is possible in well-structured digital settings. Furthermore, the study provides actionable recommendations for educators and institutions to develop inclusive and pedagogically sound online collaborative environments in mathematics education

eLearning

Effective online learning environments require the active and collaborative participation of learners to foster awareness, engagement, and understanding within the framework of the Community of Inquiry (CoI) model [18,19]. Research has shown that connective technologies, particularly videoconferencing, played a critical role in maintaining social connectedness during periods of physical isolation imposed by the COVID-19 pandemic. These digital tools not only facilitated continued interaction but also enabled pre-service teachers to engage in collaborative learning and sustained online engagement. The study primarily examined educational strategies and technological tools that support meaningful interaction and connection in virtual learning settings [19,20].

To accommodate the online format, course activities were redesigned, integrating both synchronous and asynchronous digital tools such as mobile instant messaging applications (e.g., GroupMe), collaborative digital whiteboards (e.g., Padlet), and live conferencing platforms (e.g., Zoom). The findings revealed that these collaborative strategies and resources significantly enhanced the social presence and interpersonal connections between students and instructors, thereby reinforcing the collaborative dimension of eLearning [21,22].

Collaborative Problem-Solving

- Problem-Solving

More recently, mathematical problem-solving has been associated with logical–mathematical intelligence, which encompasses the capacity to formulate conjectures, construct proofs, and apply mathematical reasoning to diverse contexts [23,24]. This form of intelligence involves recognizing patterns, appreciating symmetry, applying logical structures, and utilizing the aesthetic aspects of mathematics to address and model real-world problems [25].

Scholars argue that engaging students in mathematical problem-solving enhances not only their content knowledge but also cultivates essential 21st-century competencies such as critical thinking, creativity, and the ability to address complex, authentic problems. When students participate in extended mathematical investigations, they engage in theorizing processes, formulating and evaluating mathematical conjectures, which are often grounded in observations from specific examples. Advanced problem-solving involves recognizing structural similarities across mathematical explanations and proposing counterexamples, both of which are facilitated through collaborative dialogue and reflective exchange. These interactions underscore the pivotal role of collaboration in fostering deep mathematical understanding and promoting effective communication within problem-solving tasks [26-29].

- Collaborative Problem-Solving

Drawing on Vygotsky's sociocultural theory of learning, numerous studies have demonstrated that cognitive development is inherently a social process, fostered through collaboration involving mutual engagement, dialogue, and shared decision-making [30,33]. During collaborative learning experiences, learners may encounter socio-cognitive conflict, exposure to differing perspectives and opinions, which can serve as a catalyst for deeper cognitive growth.

The Programme for International Student Assessment (PISA) defines collaborative problem-solving as "the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution". Within this context, collaborative problem-solving necessitates joint task coordination, enabling learners to communicate, negotiate, and make collective decisions. Importantly, collaboration extends beyond the mere sharing of ideas and task delegation to encompass a dynamic process characterized by reciprocity, mutual engagement, and continuous co-construction and renegotiation of meaning [34-37].

In mathematics education, collaborative problem-solving facilitates investigation and mathematical argumentation, both of which contribute to the development and consolidation of conceptual understanding. Such engagement allows students to explore problems through creative and critical thinking, thereby enhancing their ability to interpret and navigate real-world contexts. While some research has examined collaboration in online learning tasks, there remains a notable gap in the literature regarding the specific dynamics and management of collaborative mathematical problem-solving in virtual environments. During the COVID-19 lockdown, the present researcher implemented and evaluated several collaborative approaches in online mathematics instruction [38-42]. Understanding student perceptions of these experiences is essential to inform future pedagogical practices in digitally mediated mathematics education.

Methodology

- Research Design

This study employed a qualitative case study design to explore the experiences and perceptions of university students engaged in online collaborative learning in mathematics education during the COVID-19 lockdown. A qualitative approach was deemed appropriate to capture the depth and complexity of students' lived experiences, particularly in relation to their interactions, problem-solving processes, and the use of digital tools in virtual learning environments. The case study design enabled an in-depth investigation within a real-world educational context, focusing on how collaborative learning was mediated through technology during a time of global disruption.

- Participants

Participants were third-year undergraduate students enrolled in a mathematics education program at a public university in Malaysia. A purposive sampling technique was used to select students who had actively participated in online group-based learning activities during the lockdown period. A total of 18 students (12 females, 6 males) consented to participate in the study. All participants had completed at least one full semester of mathematics coursework delivered entirely through digital platforms. Their experiences offered valuable insights into the challenges and opportunities associated with collaborative online learning in mathematics.

- Data Collection

Data were collected through multiple qualitative sources to ensure triangulation and enhance the trustworthiness of the findings. The primary data sources included:

  - Semi-structured interviews with each participant (conducted via Zoom), focusing on their collaborative learning experiences, engagement with peers, use of digital tools, and perceived learning outcomes.
  - Online observation logs, including participation in live sessions, group discussions, and collaborative problem-solving tasks.
  - Archived forum transcripts and shared workspaces (e.g., Google Docs, Padlet, WhatsApp groups), which captured asynchronous collaboration and peer feedback exchanges.
  - A short open-ended survey was also administered to capture general reflections and clarify issues raised during interviews.

- Data Analysis

Data were analyzed using thematic analysis, following the six-phase process outlined by Braun and Clarke. This included familiarization with the data, initial coding, searching for themes, reviewing themes, defining and naming themes, and producing the report. All interviews were transcribed verbatim, and observational data and forum content were organized using a coding framework aligned with the study's research questions.

Coding was conducted manually, and themes were iteratively refined to ensure they reflected the nuances of participants' experiences. The analysis focused on emergent patterns related to collaborative interactions, technological affordances and limitations, problem-solving processes, and students' perceived learning gains or difficulties.

Findings

The analysis of interviews, observation logs, and digital collaboration artifacts revealed four key themes related to students' experiences with online collaborative learning during the COVID-19 lockdown. These themes are presented below, supported by illustrative quotes from participants and observations from collaborative tasks.

- Experiences with Online Collaborative Platforms

Participants reported frequent use of a variety of digital platforms to facilitate collaboration, including Zoom, Google Docs, WhatsApp, GeoGebra, and Padlet. Each tool played a distinct role in supporting different aspects of collaborative engagement. Zoom was primarily used for synchronous discussions and group presentations, while Google Docs enabled real-time co-editing of mathematical reports and worksheets. WhatsApp served as a quick-response tool for coordination, and GeoGebra supported dynamic visualizations of mathematical concepts.

"We used Zoom for brainstorming and solving problems together. But when we needed to write the solution or prepare a document, we'd move to Google Docs so that everyone could add their part."
(Participant 7)

"Padlet was great because we could post our rough solutions, and others could comment or improve on them. It felt less formal than submitting to the teacher but still useful."
(Participant 3)

The students adapted their use of platforms depending on the nature of the task, preferring Zoom for discussion-heavy sessions and using collaborative software like GeoGebra when visual representation was essential.

- Nature of Collaboration in Virtual Environments

Despite physical separation, students were able to maintain a relatively high level of collaboration through structured group work. The nature of collaboration often mirrored traditional group dynamics, with certain students taking on leadership roles, while others contributed by organizing files or checking the accuracy of solutions.

"I was usually the one to organize our meetings and set deadlines. Others were good at explaining or solving the hard parts. It worked because we respected each other's strengths."
(Participant 11)

Collaboration also included peer explanation, negotiation of strategies, and division of tasks, especially in extended problem-solving activities. However, students noted that non-verbal cues, often present in face-to-face interactions, were lost in virtual settings, which sometimes hindered spontaneous clarification and immediate feedback.

"Sometimes I didn't understand what they meant, and without seeing them or pointing at the paper, it was hard to ask. We'd spend time just figuring out what the other meant."
(Participant 5)

- Challenges Faced in Collaborative Problem-Solving

While most students found online collaboration beneficial, several challenges emerged. These included:

- Technical difficulties, such as unstable internet connections and unfamiliarity with certain tools.
- Time coordination issues, especially when students lived in different time zones or had family responsibilities during lockdown.
- Uneven participation, where some group members contributed significantly more than others.

"One time we had a group member who didn't show up until the last day. We had done all the work, and he just added his name. That's frustrating but hard to control online."
(Participant 9)

Another common issue was screen fatigue, particularly in longer Zoom sessions, which reduced attention and motivation.

"We would start off energetic, but after an hour or so on Zoom, everyone just wanted to log off. It's not like a normal classroom where you can move around or take a break."
(Participant 14)

- Perceived Benefits of Online Collaboration

Despite the challenges, students identified several key benefits of online collaborative learning. These included:

- Flexibility in managing time and location
- Increased independence in navigating tasks
- Greater exposure to diverse approaches to solving mathematical problems
- Development of digital competencies

"I learned a lot just by seeing how others approached the same problem. Sometimes I'd be stuck, and someone would share a totally different method. That helped me think differently."
(Participant 2)

"Being able to go back to the Google Doc or recorded Zoom session was helpful. In class, if you miss something, it's gone. Online, you can review it again."
(Participant 10)

Some students also emphasized that asynchronous tools allowed more time to reflect and construct thoughtful responses, especially for those who were shy or less confident in face-to-face discussions.

Discussion

The findings of this study offer valuable insights into how university students in mathematics education engaged in online collaborative learning during the COVID-19 lockdown. The experiences shared by participants align with and, in some cases, extend existing theoretical frameworks such as the Community of Inquiry (CoI) and Vygotsky's sociocultural theory of learning, while also highlighting challenges and opportunities that emerged uniquely under the conditions of a global crisis.

- Alignment with the Community of Inquiry (CoI) Framework

The CoI framework (Garrison, Anderson, & Archer, 2000), which emphasizes the interdependence of cognitive presence, social presence, and teaching presence, is well-supported by the findings. Students demonstrated cognitive presence through their collaborative problem-solving processes, engagement with multiple solution strategies, and articulation of reasoning. The use of platforms such as Zoom and Google Docs enabled real-time discussion and co-construction of mathematical knowledge, fulfilling the role of social presence despite the lack of physical interaction.

Moreover, students' reliance on structured group roles and instructor-facilitated tasks reflected a sustained teaching presence. However, the loss of spontaneous feedback and non-verbal cues noted by participants suggests that while the CoI framework holds in an online context, the quality of presence may vary depending on the affordances of the technology and students' digital communication skills.

- Support for Vygotsky's Sociocultural Theory

Findings also corroborate Vygotsky's (1978) view that learning is fundamentally social and occurs through interaction within the Zone of Proximal Development (ZPD). Students benefited from peer scaffolding, shared responsibility, and verbal negotiation, which helped them move beyond their individual capabilities. Collaborative digital environments such as breakout rooms and Padlet walls functioned as mediating tools, enabling dialogue and joint meaning-making despite the absence of physical proximity.

However, socio-cognitive conflicts, viewed positively in Vygotskian theory as catalysts for development, were sometimes constrained by digital miscommunication or lack of clarity in online settings. This suggests that effective mediation through digital tools requires not only access but also intentional instructional design and support to maximize their potential in collaborative mathematics learning.

- Unique Insights into Collaborative Mathematics Learning

A notable insight from this study is how students redefined mathematical collaboration in a digital context. Traditional markers of collaboration, such as working on a shared problem in real-time, were expanded to include asynchronous strategies like commenting on shared documents and using visual tools like GeoGebra to support collective reasoning. Students also demonstrated adaptive agency, selecting tools that best supported the task at hand, thus revealing a form of digital fluency that is not always captured in traditional classroom settings.

Furthermore, the collaborative use of representations (e.g., graphs, dynamic diagrams) encouraged the formulation of informal conjectures and deepened conceptual understanding, an aspect of mathematics learning that is strongly advocated by researchers such as Schoenfeld (1985) and Boaler (2002).

- Lessons for Future Hybrid and Online Education

The lockdown experience has generated key pedagogical insights for the design of future hybrid or fully online mathematics education environments:

- Intentional structuring of group roles and scaffolding mechanisms is essential for promoting balanced participation.
- Tool diversity should be embraced, but accompanied by digital literacy training for both students and educators.

- Asynchronous elements offer reflective depth and flexibility but must be integrated with synchronous discussions to maintain immediacy and connection.
- Assessment practices in collaborative settings may need rethinking to account for process-based contributions and not just final outcomes.

The study also underscores the importance of digital empathy and inclusive practices, especially as online learning may persist in various forms. Encouraging students to express themselves through multiple modalities (e.g., voice, text, visuals) helps reduce barriers to participation and fosters a more equitable learning environment.

Conclusion

This study has explored the experiences of university students in mathematics education as they engaged in online collaborative learning during the COVID-19 lockdown. By investigating students' use of digital platforms, the nature of their collaboration, the challenges they encountered, and the perceived benefits, this research provides a nuanced understanding of how mathematical problem-solving and peer interaction were transformed in the context of emergency remote teaching.

The findings underscore that, despite unprecedented disruptions, students adapted to online environments with creativity and resilience. They engaged in meaningful collaboration through tools such as Zoom, Google Docs, GeoGebra, and Padlet, and navigated new forms of peer interaction, role negotiation, and shared problem-solving. These experiences affirmed theoretical frameworks such as the Community of Inquiry (CoI) and Vygotsky's sociocultural theory, demonstrating that cognitive and social engagement are both possible and productive in digital spaces, provided the learning environment is intentionally designed to support them.

- Recommendations for Instructors and Institutions

Based on the study's findings, several recommendations can be made to enhance future online or hybrid mathematics education:

- Design collaborative tasks intentionally: Assign clear group roles, set shared goals, and provide scaffolding that promotes meaningful mathematical discourse.
- Leverage multiple digital tools: Combine synchronous and asynchronous technologies to accommodate diverse learning styles and allow for flexibility.
- Provide digital training and support: Equip students and instructors with the skills needed to use collaboration platforms effectively and confidently.
- Promote equitable participation: Foster inclusive practices that support contributions from all learners, including those less confident in virtual settings.

Suggestions for Further Research

While this study offers valuable insights, further research is warranted to build on its findings. Future studies could:

- Investigate long-term impacts of online collaborative learning on students' mathematical reasoning and problem-solving abilities.
- Explore the experiences of instructors in designing and managing collaborative online tasks in mathematics.
- Conduct comparative analyses between synchronous and asynchronous collaboration models.
- Examine the role of collaborative technologies in promoting equity, especially for students with limited access or different learning needs.

In conclusion, while the lockdown created significant challenges, it also opened new possibilities for transforming mathematics education. Online collaborative learning, when thoughtfully implemented, can foster rich mathematical thinking, peer support, and digital competence. As higher education moves toward more blended and flexible learning environments, the lessons learned during the pandemic offer a foundation for building more inclusive, interactive, and effective pedagogical models.

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