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Navigating the digital age: Insights from Grade 8 mathematics learners on using technology-supported cooperative learning

Gordon Keabetswe Sekano
Research Unit Self-Directed Learning, Faculty of Education, North-West University, Mahikeng, South Africa
gordon.sekano@nwu.ac.za
Dorothy Laubscher and Roxanne Bailey
Research Unit Self-Directed Learning, Faculty of Education, North-West University, Potchefstroom, South Africa

Abstract
With the study reported on here we investigated the experiences of Grade 8 mathematics learners with technology-supported cooperative learning (TSCL) as a means of enhancing self-directed learning (SDL) in paperless classrooms. The study was conducted in 2 suburban schools in North West, 1 of the 9 provinces of South Africa. We targeted mathematics lessons in which all learners used a personal tablet in coordinated cooperative-learning (CL) settings. The study was part of a wider mixed methods project but in this article we present the results from the qualitative strand. The data were gathered from semi-structured interviews with 11 participants (6 male and 5 female), classroom observations, and a reflective research journal. These instruments were employed to document the learners' points of view, classroom interactions, and our insight into the implementation of TSCL. Data were thematically analysed and triangulated in relation to all data sources for increased credibility and confirmability. We report on 3 interrelated findings: (1) TSCL enhanced SDL through increased learner engagement and enjoyment that in turn resulted in higher levels of ownership of learning; (2) collaborative, multimodal tasks facilitated conceptual understanding and peer explanation – a phenomenon at the heart of both CL and SDL; (3) ongoing challenges such as unstable connectivity, device glitches and uneven group participation restricted the intervention's reach. We suggest that well-designed cooperative tasks, clearly assigned roles, and offline versions may enhance cooperation and SDL in mathematics classrooms. Although the study was constrained by its small, purposive sample and situated focus, it offers contextually specific evidence about the ways in which TSCL can support learner engagement, interaction and independence in mathematics education.

Keywords: cooperative learning; mathematics education; self-directed learning; technology

Introduction and Rationale
Despite decades of reform and innovation, the issue of mathematics achievement remains a concern around the world. National and international assessment including the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA) consistently show that learners struggle with basic mathematics concepts, problem-solving thinking and higher-order reasoning required for 21st-century participation (Mullis, Martin, Foy, Kelly & Fishbein, 2020). The disparity between strong and weak learners is ever increasing, especially in low and middle-income countries where access to quality resources and effective pedagogy varies among learners. South Africa mirrors these global trends but is also confronted with other systemic challenges such as the continuation of inequality, unequal access to learning technology and inconsistent levels of teacher content knowledge (Spaull & Kotze, 2015). National and international comparisons on benchmarking tests have consistently shown that South African learners' achievement in mathematics was well below the world average, with many learners lacking aspects of conceptual understanding and procedural fluency (Reddy, Juan, Isdale & Fongwa. 2019). These performance trends necessitate an immediate need for innovative technology-driven pedagogy to support collaboration and engagement, as well as learner autonomy in the mathematics classroom.

In South African schools, Grade 8 marks a crucial phase of mathematics teaching and learning where learners (ages 12–15 years) begin to develop more complex and advanced mathematical skills than in the previous phases and grapple with new concepts that are based directly on those which were introduced in the Intermediate Phase (Batanero, Chernoff, Engel, Lee & Sánchez, 2017). At this stage, learners move from processing concrete information in arithmetic to more abstract algebraic and geometric thinking where they must operate with symbols, understand representations, and build mathematical explanations (Department of Basic Education [DBE], Republic of South Africa [RSA], 2011). Such transitions frequently reveal a lack of understanding of the concepts and show discrepancies in learners' level of formal reasoning. Therefore, significant progress at this level will depend on opportunities to engage in guided exploration, peer explanation and scaffolded practice that support learners in voicing their reasoning and collaboratively correcting misunderstandings (Doo, Bonk & Heo, 2020). In the absence of such support, many learners find mathematics to be disjunctive or closed resulting in general underachievement in mathematics. Therefore, Grade 8 may be an appropriate time to introduce pedagogical reforms like technology-supported cooperative learning (TSCL) aimed at enhancing learners' conceptual knowledge and self-directed learning (SDL) abilities that are critical for successfully mastering subsequent mathematics concepts.

Research indicates that educational technology complements teaching and promote learning elements, such as interactive multimodal explanations, as well as allowing learners to explore abstract mathematical concepts through visual and digital representation (Cheung & Slavin, 2013; Li, Q & Ma, 2010). Cooperative learning (CL) is known to promote positive interdependence, individual accountability, face-to-face interaction, social skills, and group processing – crucial for enhancing deeper conceptual understanding and engagement (Johnson & Johnson, 2014). TSCL is an attempt to bring these two pedagogical traditions together, integrating digital tools and collaborative platforms to enhance co-operation between learners in settings where shared inquiry and peer explanation are at the heart of meaningful learning. In the TSCL environment, learners collaborate in groups to engage in mathematical tasks and employ digital tools for the purposes of planning, communicating or presenting solutions. This practice may help them to work together and enhance SDL wherein the learners become more responsible for their own learning by setting objectives, checking concepts, and reflecting on feedback (Knowles, 1975; Rashid & Asghar, 2016). When implemented effectively, TSCL provides a dual approach to enhancing mathematics learning: through the nurturing of collaboration via CL structures and fostering learner independence through SDL, which makes it a particularly promising strategy for use in mathematics classes in secondary schools.

The effectiveness of TSCL at Grade 8 level is important, given the influence this grade may have on learner engagement, motivation, and long-term attitudes towards mathematics (Doo et al., 2020). CL at this level of schooling may help learners develop conceptual understanding through social interaction, discussion and guided support, allowing them to build connected mathematical ideas and relationships (Klang, Karlsson, Kilborn, Eriksson & Karlberg, 2021).

This study was guided by the following research question: How do Grade 8 mathematics learners experience the use of TSCL in mathematics classrooms? We aimed to discover ways in which TSCL can promote ownership of learning and improved SDL, as these work collaboratively with mathematical concepts. In a few studies the focus was on Grade 8 learners' TSCL experiences in mathematics (Etcuban & Pantinople, 2018). Where earlier research on CL in online mathematics settings (e.g., Lazić, Maričić, Marić & Mrđa, 2022) suggests its beneficial potential, researchers rarely report on settings where no instruction is possible without any paper, and learners and teachers need to juggle with costs of the generated data and the respective connectivity. To address this gap, we explored learners' experiences at two suburban schools in the Rustenburg region of North West. At these schools, mathematics was taught using tablet-based instruction and multimodal cooperative tasks including shared Google Docs, Kahoot quizzes, short explanatory videos and Seesaw reflections. This study was part of qualitative research in a larger mixed methods project and focuses on leaners' lived experiences to provide insight into the use of TSCL for enhancing collaboration and SDL in mathematics education.

Theoretical Framework

This research is grounded in social constructivism according to which knowledge is constructed collaboratively through social interaction and mediated activity (Vygotsky, 1978). Vygotsky's theory places learning in socially organised contexts where more capable peers or adults scaffold learners' development within the zone of proximal development (ZPD). This view emphasises collaborative engagement, peer explanation and teacher mediation as key mediators in the construction of mathematical knowledge (Boke, Aygun, Tufekci, Yagin, Canpolat, Norman, Prieto-González & Ardigò, 2025). By interacting in this manner, learners could develop and reshape their mental models of mathematical concepts in a manner that deepens understanding and promotes ownership of the learning process.

Furthermore, the integration of other digital tools and resources is consistent with the tenets of the social constructivist perspective. Virtual environments provided by video conferencing, discussion forums and virtual whiteboard technology enable meaningful interaction and knowledge sharing between learners in various locations, thus enhancing inclusivity. Within these technology-enabled environments, learners are not only exposed to different points of view but are also invited to share their own perspectives, resulting in knowledge evolving as a shared communal resource (Bosch & Laubscher, 2019). The virtual nature of interaction provides flexibility and availability that transcends traditional class time, allowing learners to cooperatively learn at their own pace beyond the classroom.

CL frameworks highlight the role of teachers in task design, scaffolding and assessment of individual and group contributions (Li, R, Cao, Tang & Kaiser, 2024). CL builds on social constructivism by identifying pedagogical structures and inter-group processes that enable productive collaboration. In traditional CL models such as Student Teams-Achievement Divisions (STAD), learners work in small groups made up of different ability levels and each learner has a specific role and responsibility in the group. For instance, every learner is responsible for completing their own part of the task. At the same time, all group members work together to achieve a shared goal. When all these core elements are present, meta-analyses of

cooperative approaches have resulted in higher academic achievement, and development of interpersonal skills and motivation.

Expanding on this theoretical framework, learners' roles in exposure to TSCL was a critical factor that needed to be considered. According to social constructivism, teachers are not simply transmitters of knowledge but also develop and scaffold learning experiences to facilitate learners' understanding (Amineh & Asl, 2015). In other words, Grade 8 mathematics teachers must be confident in their ability to create CL environments that not only stimulate active participation but also foster critical thinking and problem-solving skills. To achieve this, teachers should create a supportive and intellectually challenging working atmosphere by developing tasks that encourage learners to discover mathematical concepts collectively and cooperatively (Acharya, 2023).

Adopting a similar position, Sekano, Laubscher and Bailey (2025) argue that integrating technology in TSCL necessitates that teachers are digitally competent in handling pedagogical tools to facilitate learning. Teachers need to help learners negotiate virtual environments, model responsible and ethical use of technology, and direct learners to digital content that will extend their learning to achieve curricular objectives. When they also consider a learner-centred approach, teachers can harness the potential of technology to personalise learning pathways, meeting learners' diverse learning needs, and providing real-time feedback to increase the effectiveness of CL (Doo et al., 2020).

Literature Review

CL has emerged as a pedagogical approach which successfully facilitates learners' ability to collaborate and offers substantial benefits in mathematics education (Chan & Idris, 2017), particularly when it is imbedded in a TSCL environment (Bosch & Laubscher, 2019). The five core elements of CL (positive interdependence, individual accountability, face-to-face interaction, appropriate interpersonal skills, and group processing) all contribute to the educational effectiveness of such an environment (Johnson & Johnson, 2013). Positive interdependence encourages the development of responsibility and reliance in learning, which facilitates a commitment to the group's common academic goals (Johnson & Johnson, 2013). At the same time, individual accountability ensures that each learner plays a vital role through active participation and contribution to the group's eventual success. This prevents some learners from benefiting from the collective effort without contributing in terms of effort or resources (Johnson & Johnson, 2013). Face-to-face interaction is essential in helping learners develop effective communication skills, which are necessary to share mathematical ideas or strategies for problem-solving (Johnson & Johnson, 2019). The incorporation of group processing components into the learning process ensures that learners get an opportunity to engage in metacognition, in which they can critically reflect on their collaborative activities and improve them through a cycle of continuous improvement (Johnson & Johnson, 2019). The connection between the development of collaborative competencies with CL elements and TSCL integration in mathematics learning underscores a pedagogical paradigm shift to where TSCL is considered to significantly contribute to the development of mathematical proficiency and SDL abilities.

As a subject, mathematics has been taught using the traditional method of individualised learning and rote memorisation, which can be challenging for some learners (Van de Walle, Karp & Bay-Williams, 2016). Several authors have explored the benefits of incorporating technology in mathematics classrooms (Cheung & Slavin, 2013; Das, 2021; Li, Q & Ma, 2010; Sekano et al., 2025). According to these authors the practice will help learners to become more involved and active in the subject. Bernhardt (2015:1) contends that learners in the 21st century require "interactive pedagogical experiences" if they are to be adequately prepared to address tough challenges, adjust to new circumstances, and learn how to create opportunities and networks using technology. Van Tonder (2015) concurs by arguing that if technology is used to teach the same concepts in different ways, it could make learning more interesting and enjoyable. This will in turn create a more engaged and enthusiastic learner who will want to know more about what it is they are learning, thus increasing the retention of information (Bates, 2015). This creates an opportunity to access different types of information that might otherwise not be accessible within the confines of a traditional, face-to-face classroom setting. The use of technology even creates opportunities to learn in and out of the classroom, and collaborate with experts globally (Rashid & Asghar, 2016).

Technology has the potential to connect learners and makes it possible for them to cooperate in a CL setting without the typical constraints of learning such as proximity and communication barriers (Johnson & Johnson, 2014; Mentz & Goosen, 2022). Many recent examples of TSCL demonstrate the necessity and relevance of technology in encouraging and stimulating meaningful learner engagement. The use of TSCL strategies has been shown to promote continuous, lifelong learning, because learners may have the opportunity to engage in interpersonal interactions and exchange information among themselves, gather and exchange information, and work on or complete challenging tasks, all of which contribute to a higher level of thinking (Johnson & Johnson,

2014). TSCL offers a platform for learners to engage with mathematics in a collaborative and dynamic way, which may lead to improved learning outcomes (Sekano et al., 2025). Additionally, this strategy promotes digital literacy skills, which are essential for success in the 21st century (Bosch & Laubscher, 2019).

Potential challenges of implementing technology-supported cooperative learning in mathematics education

In a study conducted by Gillett-Swan (2017), one of the dominant trends of participants was associated with personalising online learning and a subsequent decline in interpersonal interaction. Feedback from learners indicated that they felt isolated from the teachers and other participants in the course (Gillett-Swan, 2017). Schmidt, Tschida and Hodge (2016) report that participants in their study found that learners did not interact with others and that they experienced the online environment as impersonal. Furthermore, Schmidt et al. (2016) mention that the social side of internet communication is problematic. Learners frequently felt isolated, overwhelmed by other members of their class, or hesitant to voice their opinions publicly. This same expression of isolation subsequently led to feelings of loneliness, and according to Gillett-Swan (2017), it has a significant link to the dehumanising effect of technology.

Another challenge in the realisation of TSCL is internet access and connectivity. Gemiya (2020) found that learners experienced challenges with insufficient and unstable network connection. Poor internet connection impacts the time that learners join classes and participate in lessons (Aboagye, Yawson & Appiah, 2021). This implies that some learners may be unable to keep up with the pace and complete assignments (Chung, Noor & Mathew, 2020). Another study shows that even though mobile phones are commonly used to access the internet, they are not favoured as virtual tools for teaching and learning (Masters, Ellaway, Topps, Archibald & Hogue, 2016). The unaffordability of data also presents alarming and widespread concern regarding inequality (Cleofas & Rocha, 2021). According to Lembani, Gunter, Breines and Dalu (2020:71), South Africa has a significant digital divide regarding the cost and affordability of data, as well as access to and/or owning devices. These authors state that most learners have no access to technological devices, as they cannot afford smartphones, laptops, desktop computers or any devices with internet capabilities.

Given the seriousness thereof, teachers need to know about the challenges that learners are grappling with, and about innovative interventions that may help ameliorate such challenges (Mahmood, 2021). However, if interventions are planned and implemented well, the challenges may be overcome and TSCL may remain an effective strategy for increasing the SDL of Grade 8 mathematics learners.

Methodology

In this article we report on the qualitative component of a mixed-methods research design which was conducted to explore the lived experiences, attitudes, and perceptions of Grade 8 mathematics learners (aged between 12 and 15 years) in respect of TSCL. The study population was 11 Grade 8 mathematics learners at two suburban schools in the Rustenburg area of North West. The schools were unique, as they were the only two schools in the region that implemented paperless teaching and learning practices. Each Grade 8 mathematics learner used their own tablets for all mathematics lessons, replacing traditional textbooks, submission of homework, and grade reports. This unique feature made these schools an ideal choice for investigating learners' lived experiences in a fully paperless classroom environment. The participants were chosen considering some guiding criteria related to the research aims and the unique context of a paperless classroom. As the learners' mathematical experience was a critical issue in this study, purposive sampling was used to select Grade 8 mathematics learners who were directly engaged in activities of TSCL within the selected classroom setting. This purposive sampling technique facilitated the choice of participants who had experiences about the advantages and challenges associated with TSCL in a technology-rich learning environment.

The TSCL intervention was presented in eight sessions of 45 to 60 minutes delivered over an 8-week period. The sessions covered Grade 8 mathematics topics such as algebraic expressions, linear equations, and geometry problem-solving. A total of 11 learners (six males, five females) with diverse abilities were included in the TSCL intervention. The intervention was designed based on the five CL elements and included aspects of interactive multimedia like video streaming, instant messaging, video calling, interactive websites, and real-time chat sessions. Learners were divided into small groups in which the teacher assigned the roles of recorder, presenter and checker to promote individual accountability and positive interdependence. STAD as CL strategy was used in the TSCL intervention. Different technology tools were used to enhance accessibility of content. STAD is a CL strategy in which learners of different abilities work together in small groups to help one another to understand information, clarify ideas and solve problems in tasks and assignments (Tiantong & Teemuangsai, 2013). Through multimedia elements such as photos, video calling, chat rooms, audio files and voice notes learners were afforded flexible opportunities to reinforce and improve their

SDL abilities while engaging with their peers in a CL environment.

The tasks assigned in the intervention were to enhance Grade 8 mathematics learners' SDL abilities. The tasks included activities such as (a) small-group problem-solving on shared Google Docs where each team kept a collaboratively edited working document; (b) formative quizzes created by learners using Kahoot to demonstrate topical mastery, which provided immediate peer feedback; (c) short explanatory artefacts produced as narrated slide presentations (PowerPoint with voice-over) that learners prepared to teach other groups of learners; (d) reflective posts on Seesaw wherein learners described what they had learned and how they collaborated. The group activities were structured as follows: (a) the facilitator introduced the exercises; (b) the participants collectively were given a chance to learn together; (c) group members did individual work on their tasks and individual assignments were graded; and (d) rewards were given to groups that met or exceeded a given level. Competition among learners was eliminated; learners were expected to compete with themselves instead, which created a healthier, supportive and nurturing academic environment in which growth, working together, and individual progress were emphasised. The facilitator's methods were designed to assist the full group in contributing uniquely and specifically towards the success of each other, without detracting from the structure or coherence of or between group members.

Data were collected using three complementary sources: semi-structured individual interviews, classroom observations, and a reflective journal kept by the researcher. All interviews were audio-recorded with the participants' written consent and were transcribed in full. The semi-structured interviews were conducted one-on-one with each participant to explore their lived experiences of TSCL. The following questions were asked:

- What do you perceive as the benefits of TSCL in the paperless classroom? How has it influenced your understanding and engagement with mathematics?
- Could you share any challenges or difficulties that you have encountered when participating in TSCL within the paperless classroom? How did you overcome these?
- Can you describe any instances where TSCL in the paperless classroom has positively affected your motivation and engagement with mathematics? How did it affect your learning experience?
- How do you perceive the role of the teachers in facilitating TSCL within the paperless classroom? What strategies or approaches do you find most effective in supporting CL?
- Have you noticed any differences in your learning experience and academic performance since the implementation of the paperless classroom? If yes, could you elaborate on these differences?
- What recommendations or suggestions would you provide to improve the implementation of TSCL in the paperless classroom? How do you envision the future of CL in a technology-rich environment?
- Is there anything else you would like to share regarding your experiences, perspectives, or challenges related to TSCL in the paperless classroom?

Observations were conducted according to a structured protocol, with particular emphasis on on-task behaviour, interaction patterns, co-creation of multimodal artefacts, and interruptions (e.g., technical or device related). We used a reflective journal to reflect on field impressions, methodological choices and emergent analytic thoughts throughout the intervention.

We thematically analysed transcripts, observation notes and journal entries (deductive encoded) to find patterns among data sources. Coding occurred in three consecutive stages: initial open coding of each data set, focused coding to identify topics and generate possible themes, and cross-case comparison to identify convergent and divergent patterns. Triangulation was achieved by comparing themes across interviews, observations and the reflective journal to identify corroboration or contradiction. Where themes diverged, we examined contextual explanations (for example, whether an observed connectivity interruption could explain a learner's interview claim about uneven participation). We documented positionality, decisions and potential sources of bias in the reflective journal. To enhance trustworthiness, we used member checking (sharing a summary of emergent themes with a subset of participants, where possible), peer debriefing with colleagues, an audit trail of coding decisions, and thick descriptions to support transferability.

The project was approved by an institutional ethics committee (Ref: NWU-00010-21-S2). Written informed consent was obtained from each learner's parent or guardian and written assent from learners; participant confidentiality was protected through de-identification of transcripts and reporting using pseudonyms. Data were stored on a password-protected drive accessible only to the research team. Limitations of the study are the small purposive sample, of which the results cannot be generalised but are appropriate for an exploratory and interpretative study such as this; furthermore, that the participating schools were context bound.

Findings

The findings presented below should be interpreted taking the limitations of the small, purposive sample and the non-generalisability of the findings into account. The quotes presented as evidence are identified using three elements: learner (L), learners' ID, and quote number (L#: #). Excerpts for classroom observations are denoted as observation note and lesson number (e.g., Observation note,

Lesson #), and entries from the researcher's reflective journal are identified as Reflective journal, Entry #.

Overview of the Collected Data

Thematic analysis of interviews, classroom observations and the reflective journal produced three major themes: (1) enhanced engagement and motivation; (2) improved learning outcomes; and (3) challenges and limitations.

Enhanced engagement and motivation

The first theme indicates that TSCL was effective in promoting the engagement and motivation of learners. Grade 8 mathematics learners experienced more involvement and interest in learning mathematics through TSCL compared to the traditional modes of teaching and learning of the subject. This was evident from the respondents' comments:

> *I have learned a lot … You see that app … the one we were building our own maths game and play with our classmates. It was nice … I have created eight different maths games so far in my library.* (L10:8)
>
> *I feel safe when I ask them questions, because we are on the same level and we can easily relate* (L6:13).

Other participants appreciated the use of technology, which allowed learning to be more interactive and fun: "*We used apps to create interactive presentations, and even our homework assignments had these cool multimedia elements. It wasn't just reading from a textbook – we were making stuff, experimenting, and that made all the difference*" (L11:15).

We also noted that many of the learners had enjoyed working cooperatively with peers, exchanging ideas and cooperating in problem-solving. One Grade 8 mathematics learner, for example, stated: "… *another thing that stood out for me during the sessions, is that we were able to work with different learners without a need to physically get to them*" (L9:9).

Other participants mentioned specific aspects of TSCL that they enjoyed most, such as using different apps for learning, taking pictures of their work, recording, editing, and producing their own videos:

> *Recording our voices, taking pictures, and writing on them using Seesaw* [an educational platform and app that is used in schools to facilitate communication, collaboration, and engagement between teachers, learners, and parents]*, was different compared to what we normally do in our classes every day*. (L4:3)

From the observation notes it was clear that most learners leaned towards using their tablets during group tasks where they used shared Google Docs, discussed solving the task with one learner typing on behalf of the group: "*There was evident excitement when quiz answers of the group appeared on the class leaderboard in Kahoot. Many of the usually silent learners laughed, smiled and engaged in commentary about the results*" (Observation note, Lesson 3).

We made the same observation in the reflective journal:

> *Learners seemed more energetic and eager to participate compared to traditional lessons. The use of real-time tools like Kahoot appeared to sustain their attention far longer than usual. I considered that it is possible that increased level of engagement may be due to digital interactivity in conjunction with peer accountability.* (Reflective journal, Entry 3)

Data from the different sources concurred in the assertion that TSCL fostered a more interactive and engaging learning context, which led to more enjoyable experiences for the participants.

Improved learning outcomes

The second theme indicates that TSCL had enhanced the learning achievement for the Grade 8 mathematics learners. They reported that TSCL helped them to understand mathematical concepts better, develop problem-solving skills, and improve their communication and collaboration skills. For instance, some Grade 8 mathematics learners said the following: "*The group dynamic encouraged me to step out of my comfort zone and actively engage with my peers. Working together not only made maths enjoyable, but it also gave me a taste of how important collaboration is*" (L2:8).

This finding was supported by classroom observations, which captured sustained peer interaction and explanation during group tasks: "*In a factorisation lesson, learners jointly solved the questions on the same Google Doc, with one member clarifying an error while others discussed possible corrections before finalising their answer*" (Observation note, Lesson 4).

Out study raises the possibility that TSCL improves learner's communication skills. One participant noted: "*Explaining mathematical ideas to my fellow learners during our study groups forced me to articulate my thoughts clearly. Plus, listening to their perspectives broadened my understanding. It's a win-win for collaboration and learning*" (L5:6).

Other Grade 8 mathematics learners reported feeling more confident in their abilities and more willing to participate in class: "*Instead of waiting the following day to ask my teacher a question, I can just post something on our group, and anyone can assist me*" (L11:7).

We noted that learners depended less on the teacher for explanation and more on one another for assistance: "*This peer interaction demonstrates the internalisation of CL principles, although a few learners continued to dominate discussions, indicating a need for clearer role allocation*" (Reflective journal, Entry 1).

The data show the way in which CL, supported by technology, facilitated peer support and explanation as well as a broader understanding of mathematical concepts.

Challenges and limitations

The third theme reveals that TSCL created some challenges and limitations. The participants cited challenges such as technical problems, breakdowns in communication during virtual meetings and disagreements with other group members. Some of the participants commented as follows:

> *Some members will bluetick* [the act of ignoring a message sent via the social messaging app] *you* (L1:4).
>
> *You will send a text … and the next thing you are ghosted* [refers to the act of abruptly cutting off all communication with someone, typically in a social or romantic context] (L2:7).

The internet connection also seemed to be problematic for many participants: "*I don't have data at home, … I always use the school's Wi-Fi before I leave*" (L10:6).

Another Grade 8 mathematics learner expressed similar sentiments regarding technical glitches and/or unstable internet connection:

> *One of the major challenges of disruption I experienced during virtual meetings was the constant technical glitches. Sometimes my internet would drop, causing me to get disconnected from the meeting. It was frustrating to miss out on important discussions or contributions due to these technical issues.* (L3:2)

These concerns were supported in the observation notes with mentions of disrupted lessons and learner frustration: "*Several learners experienced loss of internet connections during online quizzes, and one group had to restart their tablets twice. In another group, one learner disengaged completely while others completed the activity*" (Observation note, Lesson 5).

Another challenge was disruption during virtual meetings on which one Grade 8 mathematics learner commented as follows:

> *One challenge of disruption I experienced during virtual meetings was background noise. Some participants would join the meeting from noisy environments, like cafes or homes with loud family members. The constant background noise made it difficult to concentrate and caused interruptions during important discussions.* (L8:9)

We also reflected on these incidents: "*Connectivity problems led to uneven participation, and when their devices failed, some learners became discouraged*" (Reflective journal, Entry 5).

Despite these challenges, the participants generally expressed positive attitudes towards the adoption of TSCL for the effective learning of mathematics.

The findings reported here suggest that TSCL can be a viable, effective strategy for Grade 8 mathematics learners. However, careful consideration should be given to the integration of technology in the learning process to ensure that the benefits outweigh the challenges. While certain tools cannot be used, others may need to be considered based on the needs and objectives of a specific class at a given time. Teachers must constantly evaluate whether these resources are appropriate for use in their classrooms relative to specific learning objectives and learners' needs. Moreover, for technology infusion to be meaningful, the need for equal opportunity for Grade 8 mathematics learners in terms of accessibility and digital equity must be considered. Moreover, creating a supportive and inclusive learning environment that supports learners in their exploration of technology by allowing them to experiment, may increase engagement and motivation. A thoughtful and balanced approach to technology integration can afford teachers an opportunity to harness the full potential of TSCL and to design enriching mathematics learning experiences for Grade 8 learners.

Discussion

The findings of the study reveal the positive effect of TSCL on Grade 8 mathematics learners' experiences. The learners reported positive experiences with educational technology and its impact on their active engagement and motivation echo the findings from the literature, providing further evidence that TSCL has the potential to support learners to take a more active and participatory role in the classroom. Our findings are congruent with those of Hansson (2020), as both studies reveal that the use of technological resources, such as interactive applications and multimedia content, resulted in an enhanced and enjoyable learning process for the participants. This is in line with the literature which emphasises how technology should be used to improve aspects of learners' SDL in the learning environment (Cheung & Slavin, 2013; Das, 2021; Li, Q & Ma, 2010). Technology that allows learners to explore concepts through interactive tools and allow them to create and share their own mathematics games with others, contributes to a sense of connection and engagement with learning (see L10, L6, L7). As is presented in scholarly literature, the findings of this study also highlight the significance of cooperative endeavours and interpersonal engagement in fostering a sense of commitment and dedication (Johnson & Johnson, 2014; Mentz & Goosen, 2022).

The participants' positive experiences indicate that TSCL may create a stimulating learning environment that enhances the learners' active role. These findings are consistent with the literature which advocates for technology to facilitate more meaningful participation in mathematics learning (Bernhardt, 2015; Van Tonder, 2015). Johnson and Johnson (2014) highlight the advantages of TSCL in

enhancing interaction, critical thinking, and problem-solving skills. The opportunity for learners to discuss and explain ideas in TSCL allows a deeper understanding of mathematics concepts (L5), highlighting the importance of interactive and collaborative experiences in enhancing learning outcomes (Bernhardt, 2015; Van Tonder, 2015). This conclusion is echoed in the work of Hansson (2020) who emphasises the positive impact of collaboration and learner interaction. Engagement in structured collaborative activities fostered active participation in discussions, the sharing of ideas, and joint problem-solving, which in turn enhanced learners' confidence in mathematics and increased their motivation to learn.

Bosch and Laubscher (2019) stress the importance of TSCL in promoting the development of essential communication and collaboration skills. This aspect was evident in our study – learners not only improved their mathematical understanding but also enhanced their ability to communicate effectively and work collaboratively. The development of learners' abilities to express their ideas clearly and accept others' perspectives enhanced their capacity for constructive participation in group work, fostering transferable skills applicable beyond mathematics learning.

While the benefits of TSCL are evident, our study also sheds light on challenges associated with its implementation. The participants (L1, L2) reported that technical problems in terms of poor internet access and interruptions during video calls were barriers. These difficulties have been noted by Gemiya (2020) who views internet accessibility and reliability as potential barriers to the successful implementation of TSCL. Therefore, addressing these technical challenges is important for teachers and policymakers to ensure equitable access to CL opportunities.

Additionally, communication barriers and disagreements among group members were identified as one of the challenges that the participating learners experienced during the TSCL intervention (see L1, L2), which are also mentioned by Johnson and Johnson (2014), and Mentz and Goosen (2022). To overcome these obstacles, teachers need to foster a supportive and inclusive learning environment, providing learners with opportunities to develop their communication and conflict-resolution skills.

Beyond reaffirming previous research on CL and technology integration (e.g., Johnson & Johnson, 2014; Lazić et al., 2022), our study contributes uniquely by situating TSCL in a paperless, device-rich yet data-constrained South African school context. In contrast with other studies conducted mostly in online or blended environments, our research illustrates how fully paperless classroom spaces foster both collaborative opportunities and expose the infrastructural inequities that shape learners' experiences. Thus, the findings extend the current understanding of how CL and SDL principles work in paperless, device-rich but data-constrained classroom settings, offering contextually grounded evidence that can inform classroom practice and educational policy.

Consistent with the interview findings, classroom observations and entries from the reflective journal provide evidence on how TSCL promoted engagement and collaboration in mathematics classrooms. The observation notes indicate that learners displayed engaged focus and enthusiasm during tablet-based cooperative tasks, while reflective entries highlight a shift towards an increased sense of learner autonomy and peer-peer support as perceived by us. These non-interview data sources contributed to contextual depth, illustrating how learners' participation developed across lessons and how classroom dynamics visibly changed. The triangulated evidence across interviews, observations and journal entries strengthens the validity and credibility of these conclusions. Triangulation, therefore, reinforces the trustworthiness of the interpretation and provides a nuanced representation of the potential and limitations of TSCL in practice.

Implications for Practice

The findings suggest that mathematics teachers may enhance engagement by incorporating cooperative structures into digital tasks. However, they must carefully design roles, actively monitor participation, and provide scaffolds to ensure inclusivity. Practical strategies include allocating specific roles (recorder, presenter, checker) within groups, promoting peer feedback for multimodal artefacts and designing alternative offline options such as printable versions of tasks for when connectivity is weak or unstable. Policymakers should address digital equity by investing in reliable school connectivity, supporting teacher professional development in digital pedagogy, and bearing the costs of data provision to learners outside of school hours. These implications resonate with literature on CL and digital education but are focused on the situation in South African classrooms.

Limitations and Future Research

The purposive, small sample limits the representativeness of the findings, and the study focused on only two suburban schools that may not reflect the diversity of the South African school contexts. Further research with larger, more heterogeneous samples spanning rural and urban school environments is needed to investigate contextual differences. Longitudinal designs could investigate whether the benefits of TSCL are sustained over time and whether the production of digital artefacts leads to measurable achievement gains. Comparative research could also establish

how TSCL compares with traditional CL without technology to determine the added value (if any) of digital tools.

Conclusion

This study reveals that TSCL can serve as a catalyst for reform in Grade 8 mathematic education by facilitating SDL, active engagement, and responsive peer discourse. By engaging in collaborative digital tasks, the learners were able to speak more confidently about their mathematical reasoning, communicate better with group members, and enjoy mathematics more. These findings contribute to knowledge about how technology-rich learning environments may help promote cognitive and affective development in mathematics classrooms at this educational level in South Africa, which has been under researched.

The study contributes new knowledge by demonstrating how TSCL can be integrated into a paperless, tablet-enhanced, mathematics environment to effectively foster SDL and 21st-century skills (e.g., communication, collaboration, problem-solving). At the same time, we acknowledge barriers such as poor connectivity and unequal participation and the need for explicit teacher scaffolding, which must be addressed for such interventions to be sustainable and equitable.

The practical implications of these findings are also beneficial for teachers and policymakers regarding ways to improve learner engagement with the integration of digital technologies in mathematics education. Teachers are invited to develop structured, collaborative activities with clear roles, add offline alternatives to mitigate connectivity issues, and foster a supportive group dynamic in which all learners are accommodated. In response, policymakers need to develop digital infrastructure and teacher professional development programmes that will enable teachers to use TSCL in an effective way.

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Authors' Contributions

GS: Conceptualisation, formal analysis, writing of the original draft, methodology, validation, review and editing. DL: Supervision, writing, review and editing. RB: Supervision, writing, review and editing.

Notes

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