Role of Shared Memory Space In Learning In Computer Supported Classroom

A Synopsis of the PhD Thesis

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by

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Abstract: Social interactions in classrooms in India and many other countries are limited. Networked computers can potentially support classrooms to be more interactive. It can help students share representations amongst themselves and work together on a shared virtual activity space. In research on the role of shared screens or shared virtual workspace in learning settings, less attention has been paid to contexts where learners are co-located. This thesis project looks at the impact of the shared screen in a computational game environment on mathematics learning and practices and the construction of learners' emotions and social status in classroom interactions. It was done through three separate but connected studies.

In study 1, I investigated whether a chat application (instant messaging environment) can be used to create a game environment and help children learn arithmetic skills. If yes, what features of the digital game environment are central to the learning process and why? The study was conducted in a village school with primary school students. I found that the game based on the chat application was successful in helping children learn arithmetic. Analysis drawing on tools from a distributed cognition framework suggested that the shared screen might be the central feature of the computational game environment. Next, I decided to study the role of shared screens systematically.

In study 2, using an iterative design process, I designed two versions of a simple arithmetic game by modifying the chat application used in the previous study: a solo version in which the student played the game alone and a multiplayer version in which the screen was shared, and the players could see the arithmetic moves of the other players.

In the third study, I implemented these two versions of the game in a 4th-grade classroom in a suburban school in a large metropolis in India. Classroom sessions were video recorded, computer logs were collected, and field notes were taken. Focus group sessions were held with the students. I coded a portion of the data to get at patterns of classroom interactions. Then I drew on qualitative

video analysis tools to analyse specific episodes to understand the fine timescale dynamics of dominant interaction patterns in each setting.

Results from three studies show that the shared screen served as a shared memory device, keeping a record of all the students' posts, and was entangled in the moment-to-moment dynamics of self- and peer-assessments of arithmetic. These findings suggest that thoughtful integration of networked digital tools in computer-supported learning environments can increase student-student interactions and support disciplinary learning.

Graphic overview of the thesis

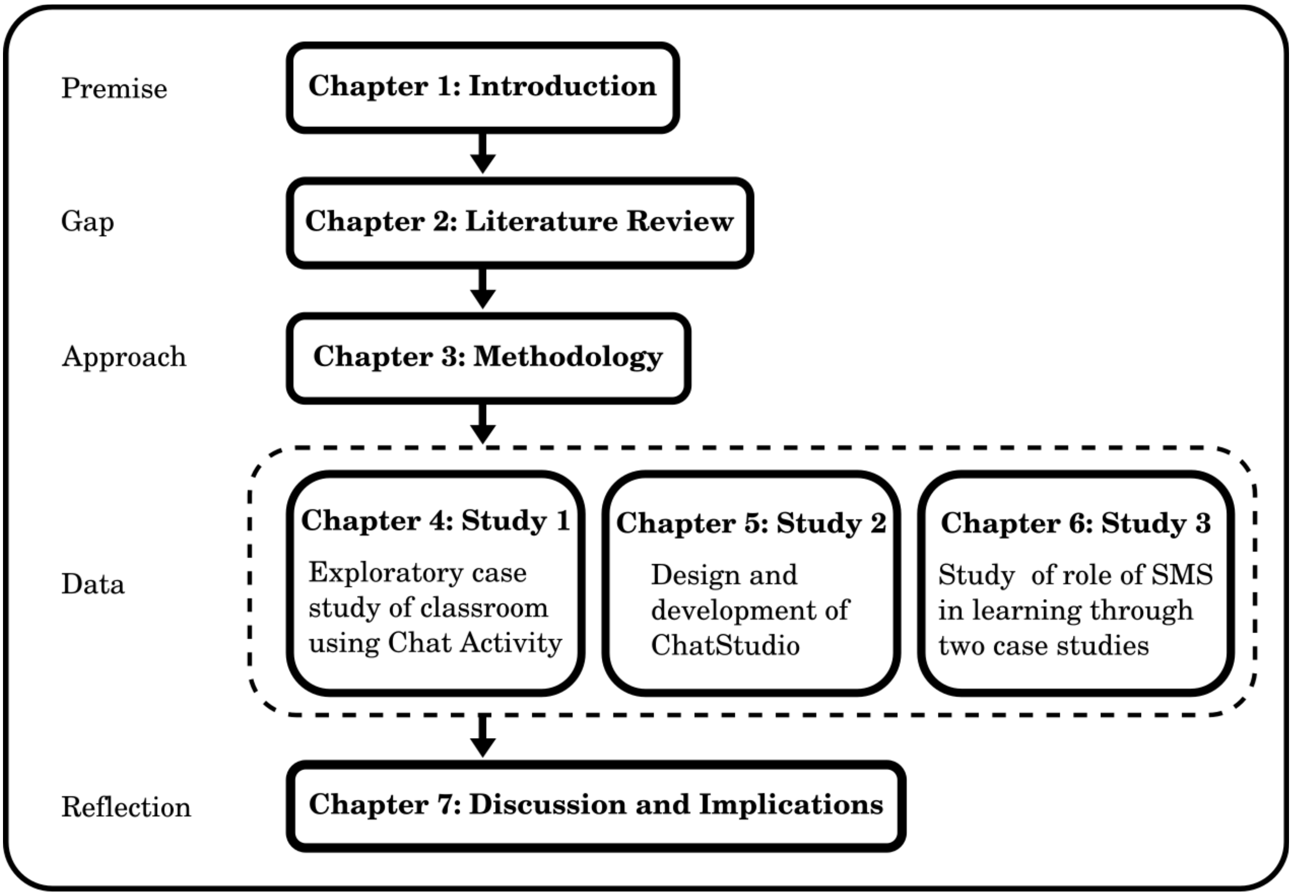

Figure 1: Organization of chapters

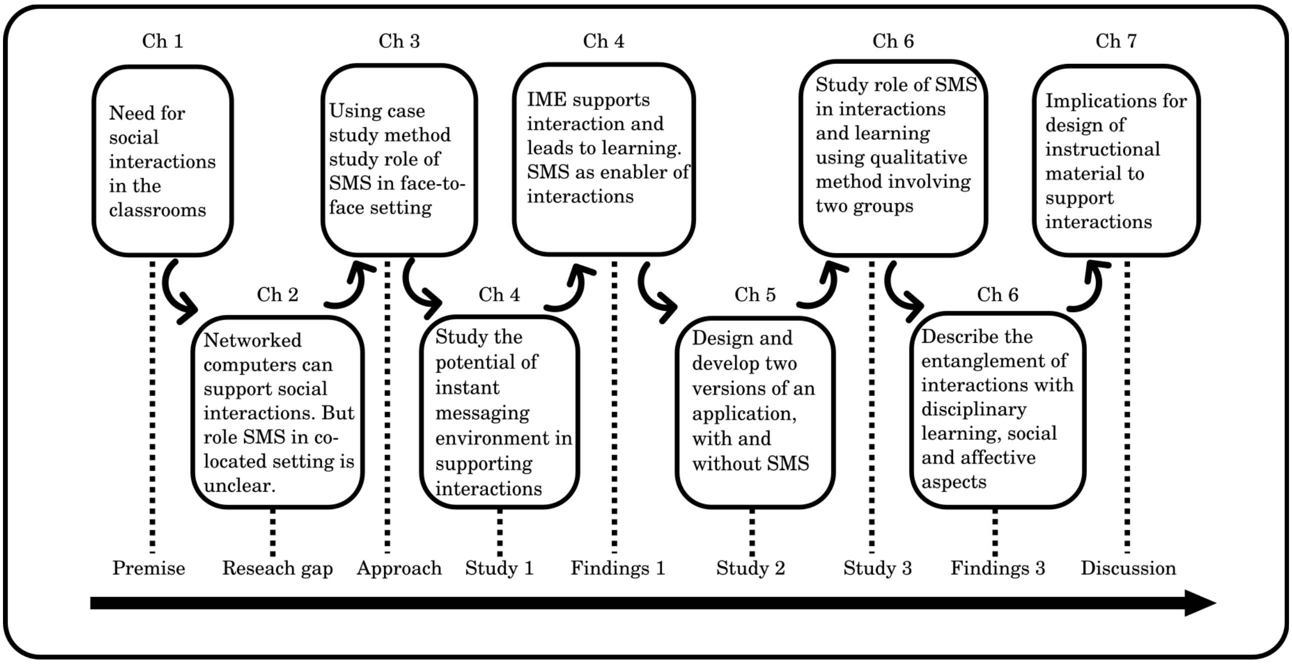

Figure 2: Overview of research trajectory

Publications based on the thesis

In peer-reviewed journal

Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

In peer-reviewed conference proceedings

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Shaikh, R., Katkam, R., Nagarjuna G., (2016). Analyzing instant messaging environment as a learning-teaching tool. Proceedings of An Workshop at the 12th International Conference of the Learning Sciences (ICLS), NIE, Singapore.

Shaikh, R., Agrawal, H., Nagarjuna, G., & Nachankar, M. (2017). Instant Sharing Makes Task More Engaging In Computer Aided Classroom. In Smith, B. K., Borge, M., Mercier, E., and Lim, K. Y. (Eds.). (2017). Making a Difference: Prioritizing Equity and Access in CSCL, 12th International Conference on Computer Supported Collaborative Learning (CSCL) 2017, Volume 2. Philadelphia, PA: International Society of the Learning Sciences.

Dhakulkar, A., **Shaikh, R.**, Nagarjuna, G., (2018) Zone of proximal development in the era of connected computers. In S. Ladage & S. Narvekar (Eds.), *Proceedings of epiSTEME 7 — International Conference to Review Research on Science, Technology and Mathematics Education*, p.214 –21 . India: Cinnamon Teal

Shaikh, R., Raval, H., & Nagarjuna, G. (2020). Impact of Instant Sharing on Classroom Activities in Computer Supported Classroom. ICME Conference, China.

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Chapter 1: Introduction

Interactions in most Indian classrooms are limited. Most of the interactions are between students and a teacher. These interactions also follow a pattern, which Mehan (1979) calls the IRE pattern. The teacher initiates (I), students respond (R), and the teacher finally explains (E) or elaborates. A recent report by UNESCO (Sarangapani et al., 2021) states that out of total instructional time in government and private schools in India, about 41% goes into teacher-centric activities and only 24% into student-centric activities. Out of the total time in the classroom, 60% of the time goes to the teacher writing on a blackboard, students copying it in notebooks, the teacher reading from a textbook, and students repeating what the teacher says. Whereas just 30% of the classroom time goes to a teacher asking questions, students writing on a blackboard, the teacher using local context and language and students working in groups. Students interacting with each other is considered a hindrance to learning, as learning is believed to be an individual pursuit. Maintaining 'discipline' is given a lot more importance. A student is considered ideal when sitting quietly, following orders, and respecting teachers (Sarangapani, 2003). The teacher is a central figure in the classroom, the sole authority on knowledge, and the go-to person for any academic or other issues.

A similar pattern can be seen in many other countries. Providing spaces for free and fruitful peer interactions remains a challenge. Social interactions are essential for learning (Vygotsky, 1978); therefore, creating space and opportunities for students to interact with peers is vital. Multiple approaches to making classrooms interactive have been proposed and studied. Some notable approaches are: a framework called ambitious science teaching (Windschitl et al., 2020), educational infrastructure to support argumentation and debate in the classroom (Bell, 2013), support to an instructor to promote productive dialogue (Webb et al., 2019), notice and interpret classroom interactions and discourse (Melhuish et al., 2019; Stockero et al., 2017; van Es & Sherin, 2002; Walshaw & Anthony, 2008) and to manage the tension in the classroom during group work (Sohr et al., 2018) and using digital technologies both standalone and networked (Baumöl & Bockshecker, 2017). The present thesis focuses on the last approach, i.e. use of networked computers to support classroom interactions, as it can potentially transform the educational landscape (Baumöl & Bockshecker, 2017).

Networked computers make sharing of representations in real-time possible. Specifically, some applications allow simultaneous access to representations and their manipulation in a digital space. Application/services such as a simultaneously editable document, a wiki or a chat environment, a multiplayer game or a virtual whiteboard are such spaces. In literature, the terms like shared activity space (Aiken et al., 2005), shared workspace (Scott et al., 2015), or shared memory space (Shaikh et al., 2020) are used for such applications/services. This thesis focuses on such shared digital spaces, which I will refer to as shared memory space (SMS); henceforth, I will use this term to talk about my work. In a socio-technical system such as a computer-aided classroom, a digital window where all the participants can create, view, and manipulate representations can be considered as an extension of the memory space of all the agents (Hutchins, 1995).

The thesis consists of seven chapters. In chapter 1, I described the poor state of social interactions in Indian classrooms and the need for creating space and support for it. In chapter 2, I review the literature on the use of networked computers in learning spaces and narrow it down to the use of shared memory space in co-located settings. Very few studies have looked at the role of SMS in co-located settings, and more attention should be paid to the affective aspects. Chapter 3 describes the methodology adopted, including research methods, study sites, data collection and analysis methods for all three studies. Then in chapter 4, I describe study 1, which was conducted to explore whether a Chat application can help children learn arithmetic. Chapter 5 describes the design and development process of two versions of an application I designed for study 3. And then, in chapter 6, I describe study 3, which was conducted to understand the role of shared memory space in learning. Finally, in chapter 7, I summarise the findings and discuss their implications.

Throughout the thesis, I reuse some text/figures/tables published in journal and conference proceedings, these publications were based on studies conducted as part of this thesis, and I have taken the necessary permissions to reuse the material. I have used a footnote to indicate where text/figures/tables are reused and the paper in which it was published.

Chapter 2: Review of Literature

Computers entered educational spaces before networked computers became commonplace. Koschmann (1996) categorised the use of computers in education into four distinct approaches. The approach that emerged in the 1960s was computer-assisted instruction. It looked at learning through the behaviourist paradigm and focused on memorising facts, and the role of a computer was to present the facts in logical order. Next came the intelligent tutoring system approach prevalent in the 1970s. It was a product of cognitivist philosophy and looked at learning in terms of mental models and representations (Koschmann, 1996). The tutoring system had computer models of students' understanding, and the role of a computer was to respond to students' errors based on models. The third approach, LOGO as Latin, emerged in the 1980s. It was based on constructionist theory and argued that children build their own knowledge. A computer provides a space and context for children to build concrete objects and learn through the process (Papert, 1980, 1993). The fourth approach is computer-supported collaborative learning (CSCL), based mainly on sociocultural theory (other theories are used but are less common), emphasising social interactions' role in knowledge construction. In the CSCL approach, a computer takes a secondary role; networked computers act as a medium through which groups and communities of students interact and construct knowledge. Even though these approaches emerged one after another, they remained popular for a long time or are still popular. Many of these approaches co-existed and are currently used. For example, the approach that Papert made famous (LOGO as Latin) and CSCL are currently the two most popular approaches in computer-aided learning. Koschman's characterisation is not all-encompassing, but it gives a bird's eye view of computer-aided learning.

Out of the four approaches mentioned above, this thesis adopts the CSCL approach. The field of CSCL has covered much ground since its inception in a workshop held in 1989 in Maratea, Italy. Most of the literature is published in the biannual conference called computer-supported collaborative learning and two journals, the computer-supported collaborative learning and the journal of learning sciences. The studies in CSCL cover co-located and remote learning spaces, from primary school to graduate studies and formal places like classrooms to informal places like online forums.

This thesis project, as mentioned above, focuses on learning in a co-located setting mediated by networked computers. I next present crucial studies in this area and highlight the research gap in the following paragraphs.

What role computers play in the learning process depends on what theory of learning designers base their applications on. This thesis draws from the sociocultural theory of learning, where computers play the role of mediators and provides a space for learners to interact.

Shared Memory Space (virtual)[1]

Learning in computer-supported spaces, where shared memory space is involved, has been studied by many researchers—starting with Roschelle & Teasley's (1995) study of a dyad collaboratively solving a challenge involving velocity and acceleration vectors. Their study demonstrated the effectiveness of a qualitative study using conversation analysis in understanding the role of a shared computational environment in providing context for social interactions among students and leading to the construction of shared knowledge. Their study also demonstrated how shared conceptual space is created through shared language, common situations, and joint action. Computer-mediated sharing helps in learning (Junco et al., 2011; Shaikh et al., 2013) by increasing social engagement (Wise et al., 2011). Shared representations act as mediators in facilitating productive conversation among learners (Suthers, 2006). In group activities, a shared workspace increases the visual awareness of the problem context and helps members better understand the problem (Müller et al., 2017).

In contrast, the absence of a shared workspace in a group activity decreases shared visual attention and activity awareness (Chung et al., 2013). That is why in collaborative activities, learners who work in independent workspaces (not in the shared workspace) also tend to work more individually and less collaboratively (Scott et al., 2015). Lin et al. (2016) used the 'shared virtual space' term to indicate the digital space that supported collaboration. Their study found that those who perceived higher collaboration also performed higher in problem-solving tasks. They also found that the collaboration improved over time. However, they also reported that those who were multi-tasking outperformed those who focused on a single task. Another study by Baturay & Toker (2019) examined the development of trust among students. They compared the development of trust in two

1 Shaikh, R. R**.,** Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

different settings; trust as a result of face-to-face communication and trust as a result of computer-mediated communication. They found that even though building trust took time in the CMC setting, it surpassed the face-to-face setting in the long run.

Shared memory space can provide context and space for social interactions. It increases visual awareness of problems and facilitates productive conversations among learners. Social interactions mediated through SMS can lead to various socio-affective outcomes, but more studies are needed to understand it better.

Games and shared memory space[2]

Games, in general, are considered a powerful medium for learning (Clark et al., 2013). Multi-player digital games involving participants' sharing and manipulation of representation can be considered games with shared memory space (SMS). The present study focuses on these types of games and their affordances.

A critical affordance of the educational games with SMS is motivating students to engage in disciplinary practices in STEM ((Bransford et al., 1990; Kirriemuir & McFarlane, 2004). This motivational effect is seen regardless of gender (Klein & Freitag, 1991b, 1991a; Papastergiou, 2009). Educational games also provide context for learning by doing and make learning fun (Kirriemuir & McFarlane, 2004).

In their meta-analysis of the literature on game-based learning, Ho et al. (2022) mention that the most helpful theory to understand the affordances mentioned above is Deci and Ryan's Self-determination Theory and Need Satisfaction Theory. These theories suggest that every human needs to feel connected, competent, and in control. During games, students experience a sense of connection with others. Peer interactions are induced by the game and mediated by the shared memory space. Social recognition as a result of performance in the game satisfies the need to feel

2 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

competent. Furthermore, the informal nature of games and the freedom to choose various aspects give a sense of autonomy.

Social games can be collaborative, competitive, or a combination of both. Games involving peer competition and collaboration have been widely researched (Johnson et al., 1981; Pareto et al., 2012; Plass et al., 2013; Shaikh et al., 2013). Studies show that both types of learning activities (collaborative and competitive) harbour a powerful motivational effect (motivation to engage in disciplinary practice) (Pareto et al., 2012).

Competition is considered more effective in stimulating students' learning progress (Cagiltay et al., 2015). It is because, in competitive mode, students are more probable to adopt performance-oriented goals (Lam et al., 2004). However, Craig et al. (2019) reported the opposite results. They designed two versions of a digital game that helped young students learn English vocabulary. One version had collaborative game-play, and the other had competitive. The games were to be played in co-located settings. They found that the collaborative version was better than the competitive version for learning. However, both were not as good as the traditional method of learning vocabulary using learning cards. Whereas having both competition and collaboration elements in a game makes it better than only a competitive game in achieving learning outcomes (Clark et al., 2016).

Ho et al., 2022), in their meta-analysis of the literature on game-based learning, also use the sociocultural theory to explain the affordances mentioned above of games with SMS. The theory considers social interactions essential for learning. Here, 'play' is considered an essential childhood activity that plays a role in a child's development (cognitive, social, and emotional) (Verenikina et al., 2003; L. S. Vygotsky, 1977). Vygotsky's idea of the Zone of Proximal Development explains why peer interactions are essential for learning.

One of the critical affordances of the game with SMS is that they motivate students to engage in the disciplinary practice. Games having an element of competition, collaboration, or both can be motivating, but what role they will play in the construction of status or emotions is unclear.

Virtual Math Teams as an example of SMS[3]

The Computer-Supported Collaborative Learning (CSCL) community extensively studied the role of networked computers in collaborative knowledge building. Specifically, Gerry Stahl (2009) and colleagues have systematically studied what I call SMS and its role in learning in virtual spaces they termed "Virtual Math Teams (VMT)". In VMT, a group of students works on an interface where they can create and manipulate representations simultaneously. The interface has a chat window, a whiteboard for drawing, and a wiki for recording and sharing group work. Users can create objects in the activity window and discuss them in chat. They can also point to objects in the activity window in chat posts.

In their decade-long investigations, Stahl and colleagues found that virtual groups can learn subjects like mathematics through interactions. They used ethnomethodological conversation analysis to unpack the moment-to-moment details of interactions in VMT. Their analysis of student interactions showed that the joint-problem space was co-constructed at the group level and not at an individual level. Construction of joint-problem space happens through temporal and sequential orientation to joint meaning-making. They also observed that sequential co-creation of representations on the whiteboard and deictic referencing to those representations in chat posts and content from past interactions played an instrumental role in achieving shared understanding among the group of students engaged in VTM. Question-answer pairs played an essential role in constructing peer relationships and regulating participation. These interactions positioned individual members in the group as more competent or as less competent. Resolving differences that arose during the discussion contributed to learning. Refer to the book by Stahl (2009) to comprehensively understand their work with VMT.

3 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

In the VMT project, participants were not in physical proximity. Their interactions were solely through networked computers. However, SMS can also be used in co-located (face-to-face) settings. Stahl studied knowledge construction in co-located settings but not as extensively as in virtual settings. In one study Stahl (2002) used micro-discourse analysis to unpack the complexity of collaborative learning of a group of students trying to design a digital model of a rocket. The analysis showed how the conversation broke down due to a problem in understanding, leading to confusion, and how the group repaired it and came to a resolution.

The work of Gerry Stahl and colleagues primarily focuses on socio-cognitive dimensions of learning. However, other studies have pointed out that researchers should not study math learning by only examining concepts, instructions, and procedures (Ramirez et al., 2012). Learning is also affected by students' anxieties and emotions (Pekrun et al., 2002; Zan et al., 2006). For example, multiple studies found that students' emotions (math anxiety) affect their math achievement, specifically those with high working memory levels (Beilock & Carr, 2005; Ramirez et al., 2012). Similarly, students' perceived math competence positively impacts math performance both in boys and girls (Erturan & Jansen, 2015; Meece et al., 1990). Students perceived competence, attitude, and emotions are constructed in and outside the classroom. Many classroom activities, such as performance in tests, games, and group work, can affect students' perceived competency. Interactions with peers and teachers may play a role in constructing students' attitudes and emotions.

In summary, this broad literature review on computer-supported interactions indicates that networked computers can support social interactions in learning spaces. However, the specific design features and their interactions with context/culture determine how learning happens and what outcomes (cognitive, social and affective) can be expected. Understanding the role of various features in digital learning environments and how they interact remains an active area of research. In this thesis, I focused on one such feature, i.e. shared memory space and its role in a digital gaming environment. The literature presented in previous sections points towards the following research gap: a) Literature acknowledges that the design features of digital learning environments determine learning outcomes but social and affective outcomes and their connection with design features need to be studied in more detail. b) literature shows that learners' cultural background plays a role in how they interact with design features. However, very few studies have been done in the Indian (south Asian) context at the primary school level. c) Very few process-based accounts of digital game environments with a focus on interactions between disciplinary learning and other socio-affective aspects.

This thesis is part of studies that design and study learning environments, digital or otherwise. Findings from the thesis contribute to the growing literature on the design and implementation of innovative digital learning environments. In the next chapter, I describe the research questions this thesis tried to answer.

Chapter 3: Methodology

This thesis project investigated a total of five research questions. However, I did not start with five questions. At the beginning of study 1, I had two questions and the remaining three questions evolved after it. The first two questions were as follows:

1) Can an instant messaging environment be used to teach arithmetic skills?

2) If yes, how does learning happen, and what features help in learning?

Based on the experience of study 1 (described in chapter 4), I formulated three more questions. They were as follows:

3) How does a shared memory space (shared screen) in a networked computational game environment influence students' engagement?

4) How does a shared memory space (shared screen) in a networked computational game environment affect disciplinary learning and practices?

5) How does a shared memory space (shared screen) in a networked computational game environment influence the construction of social status in the classroom and students' public display of emotions?

I investigated these three questions in study 3. However, during study 3 (described in chapter 6), questions 3, 4 and 5 evolved through an iterative process in conjunction with the analysis (Maxwell, 2004). The refined research questions were:

3) How was students' general engagement different between the ChatStudioSelf (CSS) and the ChatStudioGroup (CSG) settings? And why?

4) How was arithmetic use different between the CSS vs CSG settings? And why?

5) What were the patterns of differences in how students in the CSS vs CSG settings constructed status?

In CSCL, learning is viewed as a social process, a significant shift from viewing learning as an individualistic process (Puntambekar, 2013). Therefore research methods like case studies or design-based research that capture the learning process have been prevalent in CSCL since the beginning. Considering the appropriateness of the case study method (Yin, 2009) to answer research questions 1 and 2, I adopted it for study 1. It was an exploratory study where I examined a case of a village school using the Chat application to learn arithmetic. The study was conducted in a small village near Mumbai called Khairat; students of grades 3 and 4 participated in it. I was a participant observer and collected data such as field notes, interviews, and computer logs. I used qualitative analysis techniques to analyse data. Audio/video recordings were transcribed and coded to generate themes. Computer logs were matched using timestamps with significant events in audio/video and field notes. They were also used to get participants' behaviour patterns throughout the intervention. I used ideas from distributed cognition to make sense of observations.

In study 2, I decided to develop a digital game called ChatStudio by modifying the Chat application used in the previous study. I developed two versions to have a contrasting case for study 3. In CSCL, design-based research is one of the most common methods for designing and developing learning tools (Stahl & Hakkarainen, 2021). However, I used a process similar to product design, where application development goes through an iterative process of design, testing, and reflection (Stahl & Hakkarainen, 2021). It had some similarities with the DBR process. Study 2 happened in the g-lab of Homi Bhabha Centre for Science Education, Mumbai. Two versions of ChatStudio applications were tested first in the Gnowledge lab[4] and later in school during study 3.

Whereas for study 3, I adopted a two-case study design. I chose two cases instead of one because the second case (without a shared memory space) provided observations that helped me understand the role of shared memory space and separate it from other aspects. Study 3 happened in a semi-government school in a suburb of Mumbai. Forty-five students in grade 4 participated in the study. They were divided into two groups. One used ChatStudioSelf, and the other used ChatStudioGroup. I played the role of teacher and observer. Forms of data collected included field notes, audio and video recordings, focused group discussions and computer logs. For analysis, I used tools from conversation and interaction analysis to tease out the effect of SMS in emerging patterns of interactions in both cases.

Chapter 4: Exploring the potential of instant sharing as a teaching-learning tool

As mentioned above, this thesis includes three studies. In this chapter, I describe study 1. This study started as a reaction to a request from a village school teacher with whom Gnowledge lab and I were working. The school had a project called One Laptop Per Child[5] (OLPC) running; therefore, each student had a laptop designed by MIT's Media lab. The laptops were called XOs and designed based on Papert's 'Children's Machine' (Papert, 1993). The XO does not have content; it has tools students can use to construct knowledge. Students' work is automatically catalogued into a journal, and each application has solo and collaborative modes. Its applications are called activities that help

4 https://www.gnowledge.org/
5 https://laptop.org/

children learn various skills and concepts. However, the teacher from that school could not find any good activity to help children learn arithmetic. He said his students are struggling with number operations, but there are no suitable activities for it currently, and he asked me if I could help. Therefore, this study aimed to design an activity to help children learn arithmetic. I also decided to study the process and investigate if the activity works and, if it does, what features are crucial in learning.

I had observed students of this school using "Chat Activity," an instant messaging environment to play simple word games. I decided to use the same application to play number games. I devised a few simple rules that might make the game joyful to play and learn. In the game, 'stepping number' is the number that is added repeatedly and 'starting number' is the number you start with. Fig-1 is an example of a game in which four students decide that they want to play a game with 4 as the stepping number ("Let's play add 4 game") and 4 as starting number ("start with 4"). As soon as the number pair is decided, the game starts; each student adds the stepping number to the starting number (4+4), then posts the result of addition, i.e., 8 on the screen and again adds the stepping number (4) to 8 and posts the result, i.e., 12 on the screen. All the students keep posting numbers on the screen until someone declares they won. At that moment, everyone takes pause and checks the claim of that student by checking all their numbers. If the numbers are correct, that student becomes the first to cross the last number, and if someone finds a mistake, the student starts from the previous step. The game continues until all the students reach a three-digit number in the series.

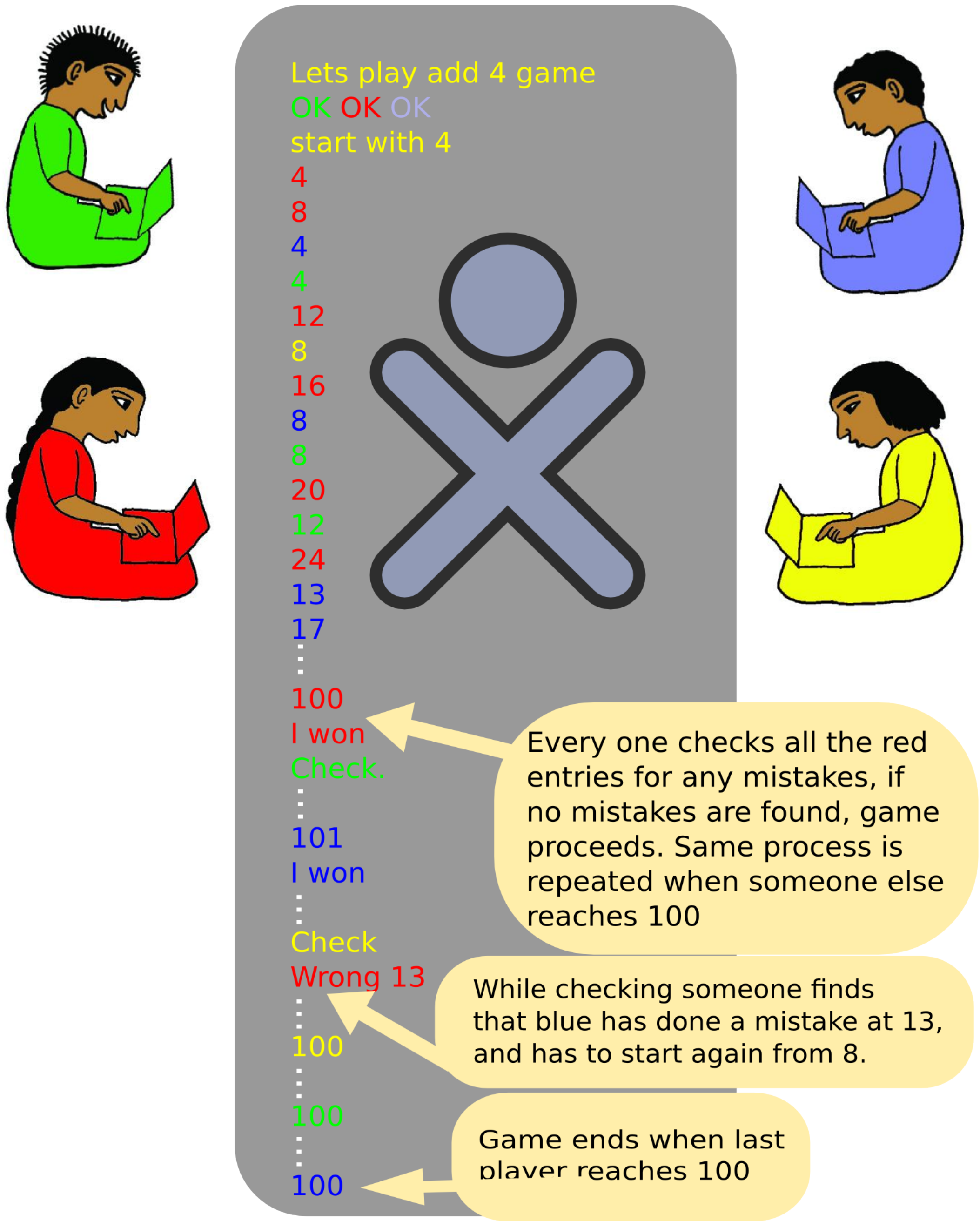


Fig 1: Illustration of number game[6]

Before students played number games, I checked their arithmetic proficiency through personal interviews. Then games were introduced to the students, and they were encouraged to play the number games. I visited the school once or twice every week. During my visit, I participated in and observed the game. I recorded my observations in the field diary and collected logs from all the laptops. At the end of the intervention, I again checked students' proficiency in arithmetic through

6 Shaikh, R., Nagarjuna, G., Chandrasekaran, S., (2013). Socialising mathematics: collaborative, constructive and distributed learning of arithmetic using a chat application. In Nagarjuna G., Arvind Jamakhandi, and Ebie M. Sam (Eds.) Proceedings of epiSTEME - 5, pp. 321 - 327. Mumbai: HBCSE, TIFR

personal interviews. A comparison of students' understanding of arithmetic before and after the intervention showed improvement. Students played the game in and out of the school, suggesting they enjoyed it. Students often interacted with each other to assess each other's work. Observations showed that students discovered and devised new strategies to perform number operations faster and more accurately. Those strategies spread through the classroom soon after their discovery. I also saw a few socio-affective changes. For example, a female student considered below average by the teacher and peers showed gradual improvement in her arithmetic skills in the game context. The teacher and students' perception of her academic abilities also changed. My analysis was inspired by distributed cognition (Hutchins, 1995); I used to understand what was happening while children played number games. The externalisation of representations can offload memory and lead to a closer focus on the essential task at hand. The game's design also provided quicker feedback to the students by providing them with a self and a peer-to-peer assessment model.

Chapter 5: Design and Development of ChatStudio[7]

While reflecting on the observations from the pilot study, I asked myself why the number game worked and what features of the game were central to it. I imagined if such a game could be played with laptops, paper and pencil, blackboard and chalk, or verbally. If the game is played verbally, I anticipated that there might be multiple speakers simultaneously, and it would be harder for students to perform calculations and monitor others' numbers simultaneously. Monitoring others' numbers for assessment was an essential part of the game. If the game was played on paper or a blackboard, students could monitor others' numbers, but only 2-3 students could have played at any given time. Having a larger group play simultaneously was important. The shared screen served as a Shared Memory Space (SMS), providing instant access to one another's posts. This supported cross-talk amongst the students, where they could assess their and others' work, supporting and/or contesting

7 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

their work. In this way, I felt that the shared screen, as an SMS, supported students' individual and collective learning. Thus, in my view, the shared screen was one of the game's central features and played a role in generating the patterns of learning and interactions we were observing.

Based on study 1, I formulated new research questions mentioned in chapter 3. I needed to modify the existing chat activity and create two versions to answer these questions. The existing Chat Activity was not explicitly designed for learning arithmetic; therefore, I decided to modify it into an application customised for learning arithmetic skills. I decided to call the new application ‘ChatStudio’ and two versions of it as ChatStudioSelf (CSS) and ChatStudioGroup (CSG). The design and development of ChatStudio happened in study 2, described in this chapter. As mentioned in chapter 4, I used XO laptops developed under the OLPC project. The operating system running on XO laptops is a 'free software'[8] called Sugar-Learning Platform (SLP). This feature made it easy for the team at gnowledge-lab to get the source code of Chat Activity and use it to create the ChatStudio application.

As mentioned in chapter 3, for development, we used an iterative process of design, testing and reflection. During the development, I used guidelines created by Kirriemuir & McFarlane (2004) by reviewing the literature in the educational game area: 1) A task that the player can complete, 2) Focusing on the task, 3) A task with clear goals, 4) Immediate feedback, 5) Deep but effortless involvement, and 6) Exercising sense of control over one’s action. The testing part of the development process happened at the g-lab of Homi Bhabha Centre for Science Education. Various features of the ChatStudio were tested with interns visiting the g-lab. Another round of testing happened during study 3 in school with 4th-grade students. Two programmers, who wrote the code for the ChatStudio, visited the school with me and observed the functioning of both versions of the ChatStudio. The table below and fig-2 describes the similarity and differences between the CSS and CSG versions:

8 Free software is a software released under a licence that allows users to use, study, change and distrubute the software or versions of it freely.

Table 1: Comparison of digital environment[9]

Features	ChatStudioSelf	ChatStudioGroup
Solo/Multiplayer	Solo	Multiplayer
Mode	Addition and Subtraction	Addition and Subtraction
Difficulty level	Easy, Medium and Hard	Easy, Medium and Hard
Option to select a custom number pair	Yes	Yes
User specific color coding	Yes	Yes
Score card	Yes	Yes
Accuracy graph	Yes	Yes
Reaction time graph	Yes	Yes
Reward as badges	Yes	No
Option to invite others to play with you (Share button)	No	Yes
Automatic saving of details of each session of the game	Yes	Yes

Along with the digital features, the rules of the games were also very similar. Except for a few rules. The following table list all the steps in both versions of the game.

Table 2: Comparison of digital environment[10]

Steps in the game	ChatStudioSelf	ChatStudioGroup
Student starts the ChatStudio application	Yes	Yes
Student/group decides the mode	Student	Group (including the teacher)
Student/group decides the difficulty level	Student	Group (including the teacher)

9 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

10 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

Student/group decides the number pair	Student	Group (including the teacher)
Interaction type	Student-machine, student-teacher	Student-student, student-teacher, student-machine
Support during game	Teacher	Peers and teacher
Assessment	Self and Teacher	Self , Teacher and Peer
Reward at the end of the game	Digital badge	Ranking on the scorecard

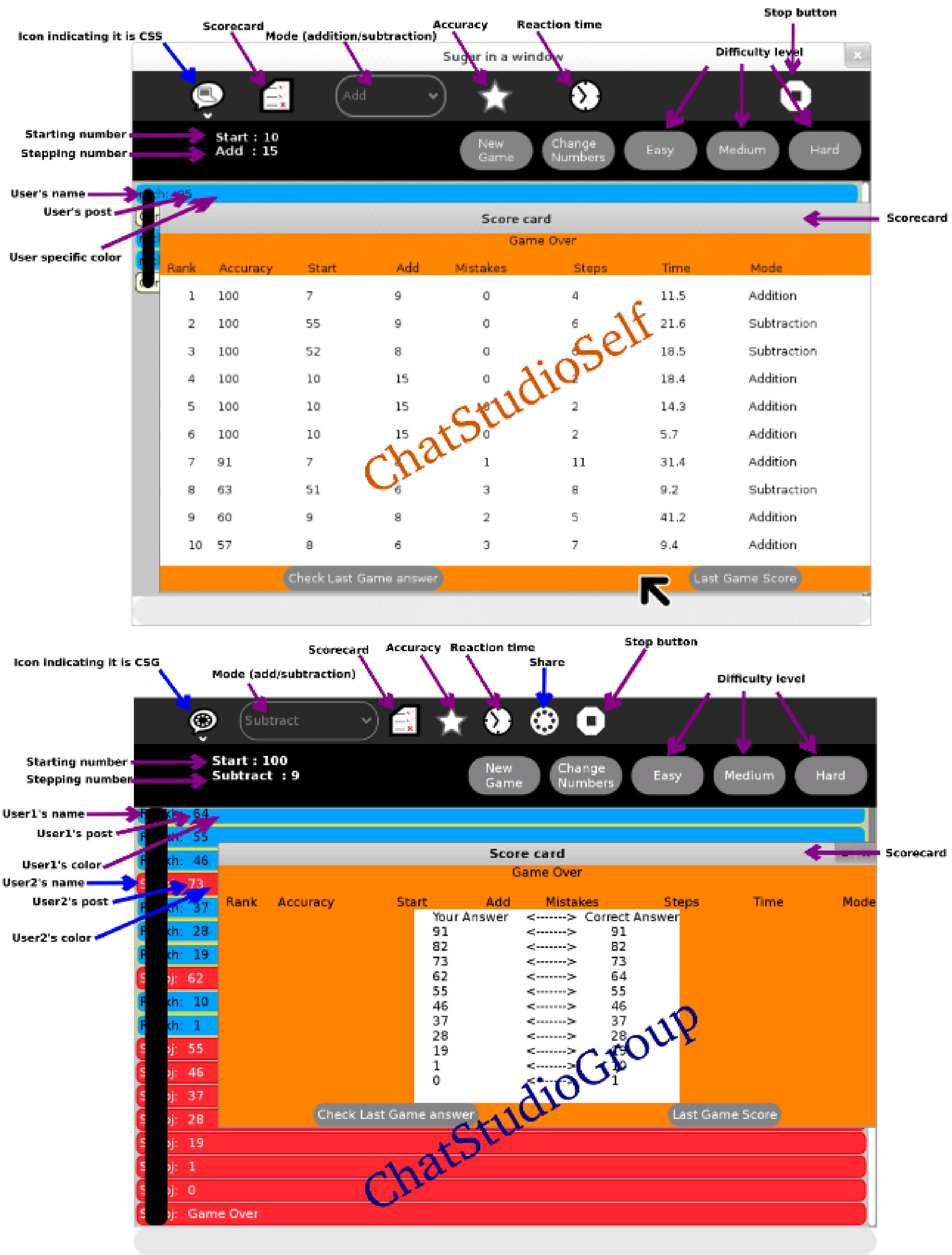


Fig 2: Two versions of the ChatStudio game and their features[11]

11 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

Chapter 6: Understanding the Role of Shared Memory Space in Construction Knowledge, Status and Emotions

The objective of this study was to answer research questions 3 to 5 mentioned in chapter 3. In order to do that, I selected forty-five students from grade 4 (16 F and 29 M) and divided them into two groups. One group was assigned to the "ChatStudioSelf" (CSS) setting and the other to the "ChatStudioGroup" (CSG) setting. Names of the groups were given based on the version of the ChatStudio application they used. Students were allowed and not discouraged to interact in either setting. Most of the students were first-generation learners from migrant families. The medium of instruction was Marathi (regional language), and the laptops students used had Marathi language support. As mentioned earlier, classroom sessions were audio and video recorded. Computer logs were saved, and field notes were taken. I analysed the video records using tools from interaction and discourse analysis and supported it with transcripts from computer and field notes. Records of students' activity on the virtual platform informed our analysis of students' strategies to solve arithmetic problems. The analysis focused on student-student and student-mentor interactions and students' emotions and behavioural patterns. I compared the patterns of interaction between the settings and engaged in a detailed analysis of specific episodes that were interactionally rich (most such episodes were in the "ChatStudioGroup" setting).

The result of the arithmetic proficiency test conducted before the intervention showed that students from both the settings (CSS and CSG) were similar ($p=0.436$). The post-test showed that each group performed better than their performance in the pre-test, and the p-value for the CSS group was p=0.00002956, and for the CSG group, it was p=0.00008645. However, there was no significant difference in the two groups' performance on the post-test (p=0.8263).

Engagement and Interaction patterns

To check the students' engagement level with ChatStudio (research question 3), I analysed the computer logs from both settings. I checked how many students were playing the ChatStudio game each day and how many students accessed other apps on the laptop during each session in each setting. This was used as a coarse-grain measure of the level of students' engagement. A difference was observed in the engagement level in the two settings. In Fig. 3a, we can see that at the beginning of the intervention, students from both settings engaged with the game. However, as time passed, the engagement level in the CSG setting more or less remained constant, whereas in the CSS setting, it came down. I also checked how the ChatStudio game fared against other applications (Maze game, painting app, word processor, Music composer, Turtle LOGO programming app, etc.) on the laptop. Students were free to choose any application they liked. Fig. 3b shows a difference in students' engagement with other applications in both settings. The students from the CSS setting used the other apps more than the CSG setting students. A comparison of both graphs shows that in the CSG setting, the ChatStudioGroup app was more engaging than the other apps. In the CSS setting, the other apps were more engaging than the ChatStudioSelf app.

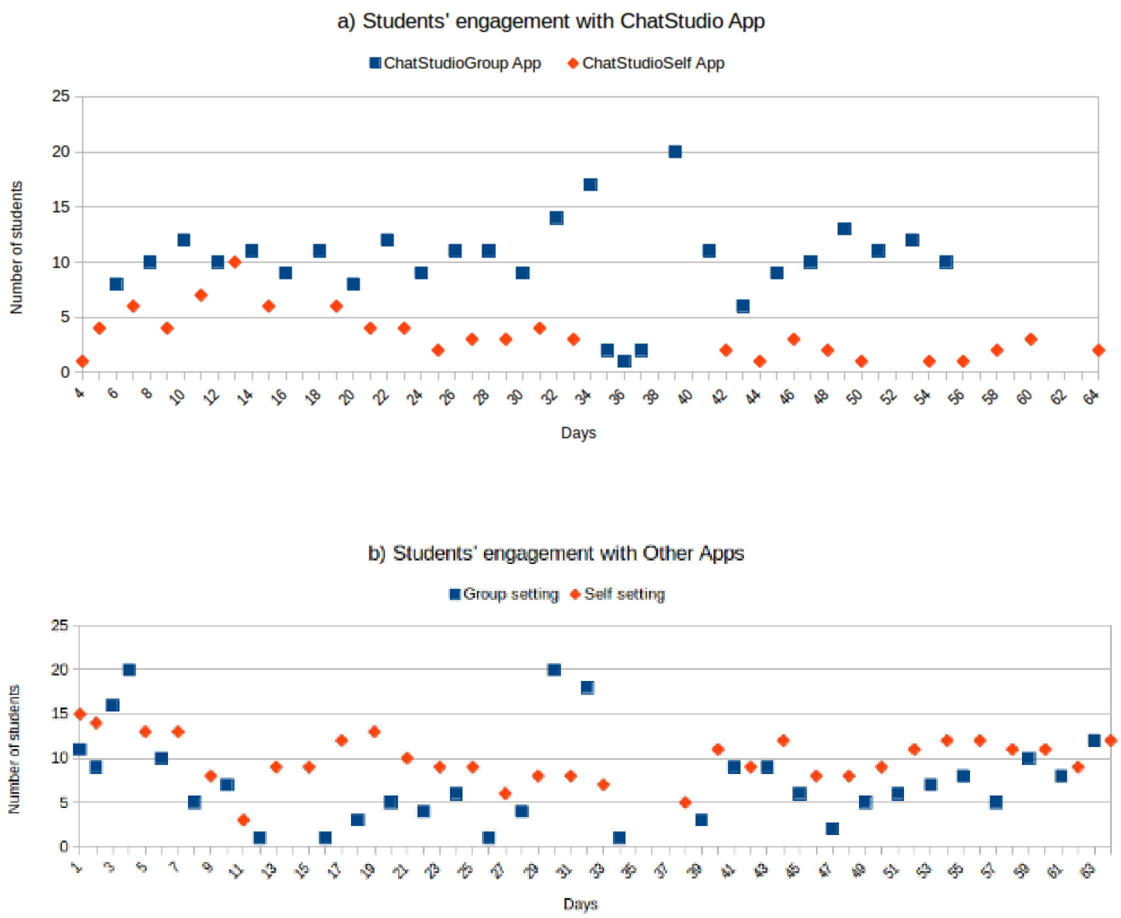


Fig-3: Comparison of students' engagement with ChatStudio in Self (N=22) and Group (N=23) settings; and (b) comparison of students' engagement with other applications during the entire intervention[12].

Next, I checked interaction patterns in both settings by coding 15 mins of video from each setting to inspect interactions between students, the teacher and machines. In fig-4, we can see that pattern of interaction in the two settings was different. In the CSS setting, the most prominent interactions were between student-teacher. Whereas in the CSG

12 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

setting, that was not the case. Inspecting the video to look at the context of the interaction in these events, I noticed that the contexts of interactions were also different in the two settings. In the CSS setting, the contexts for these interactions were students seeking evaluation and appreciation from the teacher for the work done, taking the teacher's help in troubleshooting a technical issue, or seeking help with arithmetic. The pattern is similar to the interaction pattern in the traditional class mentioned in the introduction, where the teacher is the primary source of information and assessment.

In contrast, in the CSG setting, the interaction contexts were students' assessing each others' work, celebrating success, having a group discussion around the game (e.g., to decide on the starting and stepping numbers), reporting others' mistakes to the teacher, and litigating their cases with the teacher. Here, sources of knowledge and information included the other students and the shared screen, which kept a record of everyone's gameplay. Later I present a few vignettes of such interactions.

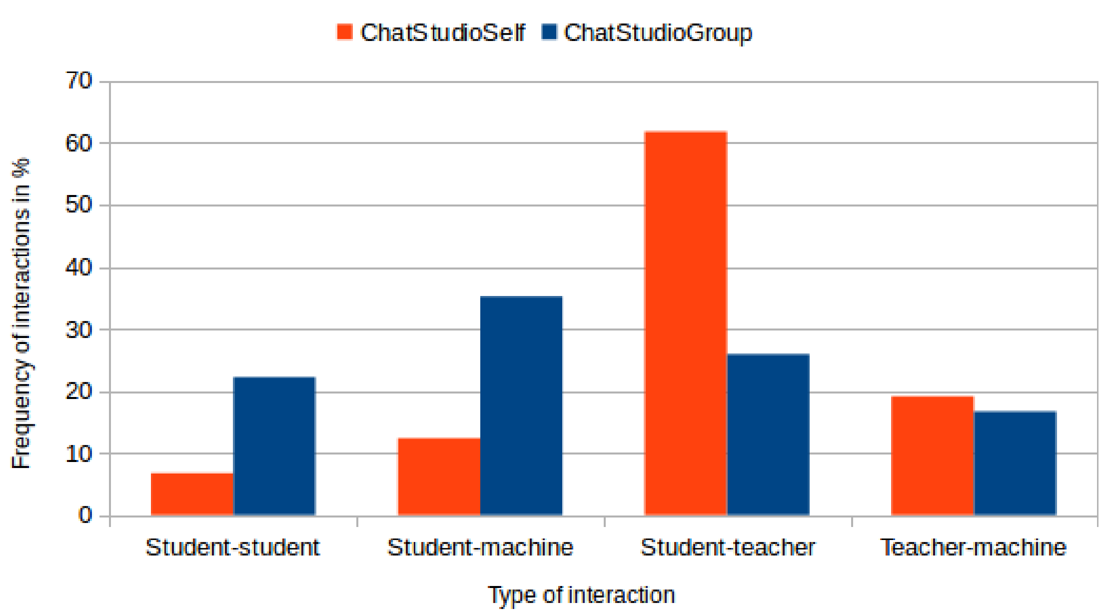


Fig-4: Graph showing the number of different interaction events during a 10-minute segment from each setting[13].

Learning of arithmetic

Regarding learning arithmetic (research question 4), I looked at what kinds of number pairs students were choosing during gameplay and what strategies they used to advance through the game. Computer logs showed that the students from the CSS setting tried 14 different number pairs, whereas those from the CSG setting tried 14. Further inspection revealed that the students from the CSS setting chose simple number pairs such as (10 and 10) or (20 and 20) and chose some number pairs repeatedly. No such pattern was seen in the CSG setting, even though their total pairs were high. In the CSG setting, there were 21 pairs selected just once, 16 pairs selected twice, 4 thrice, 1 pair four times, and 1 pair seven times (5&5). With the exception of the number pair (5, 5), they did not select simple pairs such as '1 and 1' or '10 and 1' or '20 and 20,' which were used repeatedly in the CSS setting. There was also a difference in the strategies that students used for gameplay. Students used strategies like counting up or down with the help of fingers, counting up or down by speaking aloud, sequentially adding or subtracting the stepping number mentally, decomposing to the nearest simple number and regrouping later, and using multiplication tables to do additions. Students from the CSS settings predominantly used counting up or down with the help of fingers and the counting aloud strategy. The use of more complex strategies was less common in the CSS setting. The students from the CSG group used all the strategies mentioned above; however, I observed progression from simple strategies to complex ones over the course of the intervention. One of the

13 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

strategies that drew our attention was using multiplication tables for deciding number pairs and stepping. Students in both settings discovered that multiplication tables could be used for working through the game in certain situations. The strategy was more widespread in the CSG setting, with 13 students using that at some point during the sessions, compared to only three students in the CSS setting.

Assessments, Status, and Relationality in interactions

One of the things that jumped out at me during analysis were that many of the student-student and student-teacher interactions were structured as arithmetic assessments. Arithmetic assessment, academic status, and social relationalities were co-constituted in these moments. However, the CSS and CSG settings differed in how these moments were configured. For example, Fig-5 is an example of such a moment in which Sonali, a student from the CSS setting, waits and tries to show her achievement (digital badge) to the teacher. She moves to the next game session only after the teacher sees the badge and says well done. The teacher played a central role in the CSS setting, and students also perceived it similarly. In the CSG setting, I saw a change in student-teacher interactions. Students argued their case with not only other students but also with the teacher. No such change was observed in the CSS setting.

Fig-5: Chronologically arranged snapshots of the classroom scene and Sonali's computer screen to illustrate assessment interactions between a student, Sonali, and the teacher[14].

Student's attitude

The fig-6 shows an episode where I notice a female student's attitude change. The student's name is Samita, and in this episode, she acts differently from her previously observed behaviour. Here she did her calculations, came up with an answer, and stuck to it when others confidently touted their numbers as correct. She did not change her number to match what others were saying. After much back and forth between students

14 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

and teachers, when the teacher declared that she was correct, I saw her self-confidence boosted by her expressions. Soon after, she interacts directly with a male student and tries to come out in the open to celebrate. This deviates from her previously observed behaviour as a shy student.

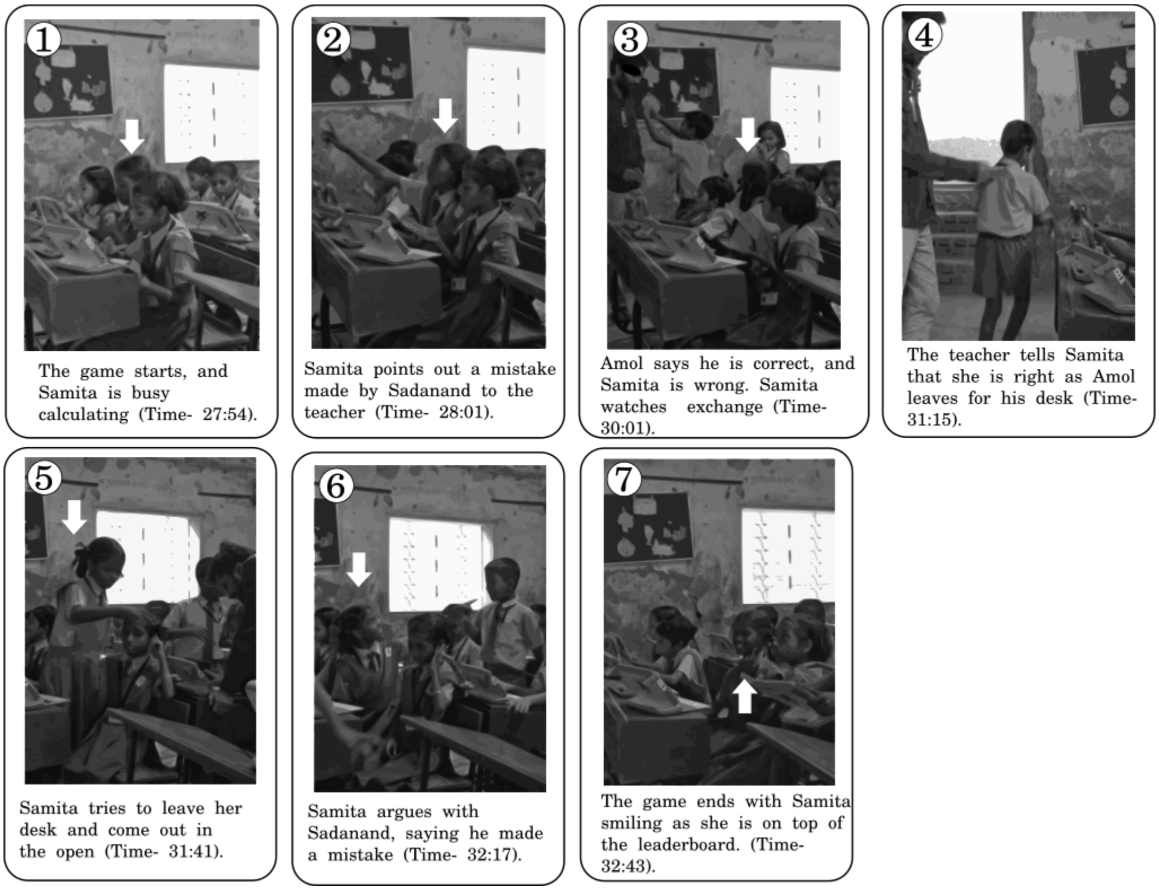


Fig-6: Chronologically arranged snapshots of the classroom scene showing the sequence of events that lead to a boost in Samita's confidence[15].

Status, Trust, and Friendship

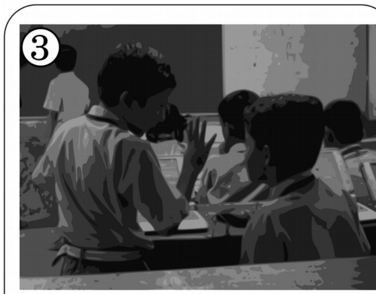
In the final vignette, I show how pre-existing relations among the students influenced whom they looked to for help. The episode (fig-7) starts with Nikhil pointing out that Krishna made a mistake. Krishna looks unsure about Nikhil's claim, but he does not respond to him even though he is sitting at an adjacent desk. Instead, Krishna goes to Aakash, even though Aakash is not playing the game in this session 1 (See the fig-7). He

15 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

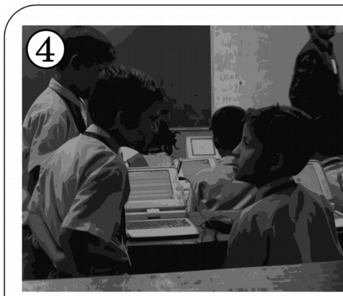
uses Nikhil's laptop (as Nikhil is away from his desk) to show him the game screen numbers and ask his opinion. They discuss, and Aakash tells Krishna that he is correct and the answer should be '50'. The whole conversation between Aakash and Krishna was in a very low voice, as if private. I suspect that Krishna feels safe with Aakash because they have a history of pleasant and friendly interactions. Even though Aakash is not playing the game in this session, he has been a regular player, and on that day, he joins the game in later sessions. Both are equally good at the game (in later sessions, both score 100% accuracy); they have helped each other in the past. They have built a friendship through regular interactions in the game context. Krishna does not have such a relationship with Nikhil.

Krishna (L) looks for help from Aakash (R), as Nikhil had pointed out that he had made a mistake. Krishna is confused and moves physically close to Aakash (T- 16:30).

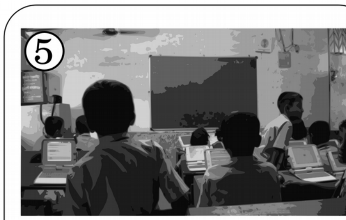
Krishna uses Nikhil's laptop to show Aakash the numbers on the game screen (T- 16:33).



In a low voice, Krishna asks Aakash what the number will be if he adds five (shows five fingers) (T- 16:37).



Krishna attentively listens as Aakash tries to explain that it will be '50', and he is correct. The conversation is in a low voice (T- 16:40)



Krishna moves back to his seat. The whole conversation between Aakash and Krishna was in a very low voice, as if private (T- 16:47).

Fig-7: Chronologically arranged snapshots of the classroom scene showing the interactions between Krishna, Akash and Nikhil[16].

Chapter 7: Conclusion and Discussion

The thesis, through multiple studies, examined if chat application can make face-to-face classrooms interactive and, if it does, what role shared-screen plays in learning. Study 1 confirmed that using an instant messaging application along with classroom norms could facilitate more interactions in the classroom. Studies 1 and 3 confirmed what others (Lomas et al., 2017) had reported: simple rule-based games can be engaging and motivating. In parallel to other studies in the literature (Plass et al., 2013), I also saw a higher level of engagement when the digital interface and classroom norms encouraged peer interactions and peer assessment.

In study 3, I found that the pattern and context of interactions in both settings were different. The interaction pattern in the CSS setting was similar to that in the traditional Indian classroom (Sarangapani, 2003). However, the pattern from the CSG setting with SMS differed from the traditional and CSS classrooms. The students not only interacted with the teacher but with other students, both face-to-face and via machine.

Learning happened in both settings (with or without SMS); however, my analysis showed that having SMS in the class changed the learning process. Offloading representations and instantly sharing them enabled certain interactions. I saw that students from the CSG setting monitored others' posts on the ChatStudio screen and used it for several purposes: to check the accuracy of their calculation, get a hint, assess others' work, and litigate their

16 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

case with other students and the teacher. Interactions where students assessed their own or peers' work were instrumental in the learning process, and the shared screen was entangled in the moment-to-moment dynamics of these assessment events.

My findings were similar to Hoang et al.'s (2022) finding that students have a positive attitude towards peer assessment, and quality is also better when they know that their peer-assessment activities were considered in the final score. The assessment activity also helped students travel from the periphery (novice) to the centre (expert). It happened as students became independent in developing skills needed to complete the task in the ChatStudio game (Rada, 1994) as one could play the game by following and copying someone's numbers. However, one needs to think and reason to assess others' work.

In study 3, the students in both settings (with and without SMS) could choose any activity on the laptops. Nevertheless, they chose the ChatStudio application and interacted with it. What is the motivation to use the ChatStudio application? Both versions of the ChatStudio satisfy two basic needs of students, as Deci & Ryan (2012) suggested. Students were free to choose (autonomy), and students could opt for the difficulty level and number pair of their choice and complete the task (competence), as seen in Sonali's case. However, I saw the difference in engagement level in both settings, and I think the third need, i.e., the need to feel connected with others, was missing in the CSS setting. That could be part of the explanation for why students from the CSS setting were not as motivated as students from the CSG setting. The shared screen played a role in creating a feeling of connectedness in the CSG setting. Representations on the screen initiated and mediated most of the interactions.

The episode involving Krishna, Nikhil and Akash, reported in chapter 6, suggests that the relationship with the learner also matters along with the knowledge level of the peer/adult. Epistemic interactions can be more powerful for learning when the participants are friends (Takeuchi, 2016). Relationships of this kind can develop when students can freely interact for a long time, and there is a context for interaction. They can also lead to trust development (Baturay & Toker, 2019). Support through such relationships may explain the observed difference in the level of engagement in the two settings. Having shared representation is a mediator and facilitates productive conversation among learners (Suthers, 2006). Conversations can contribute to the construction of relationships.

Implications[17]

Implications for instruction using digital games for mathematics learning

Findings suggest that classroom norms are essential for creating space for social interactions. Therefore, teachers/educators should design classroom norms that can support more peer-to-peer interactions. Furthermore, such interactions can support students in learning via instructional games. Competition in an instructional game can help students engage with the task so that competition can be included as an instructional strategy at times. However, there should be careful instructional deliberation on how to balance competition and collaboration. The work also suggests that having friends in mathematics class can help students learn from mistakes, and friendships can provide

17 Shaikh, R. R., Nagarjuna, G., & Gupta, A. (2023). Investigating the role of shared screen in a computer-supported classroom in learning. Education and Information Technologies, 1-48.

safe interactional contexts. Therefore, game design should include opportunities to build friendships.

Implications for the design of instructional games

Findings also suggest that, within particular classroom contexts, games that support peer interactions might be better at helping children learn than ones that only support student-machine interactions. A space that allows externalisation and instant sharing of representations among participants have certain advantages. Therefore, designers of instructional games should include features that allow the externalisation of representation.

Findings from studies in this thesis echo the suggestions by other researchers that instructional games should be as simple as possible (Lomas et al., 2017), especially when designed for young students. Games should not consume considerable time to learn the rules. While designing the games, designers should ensure that learners are interacting readily and have the option of interacting with any member privately when necessary. Games should have features/rules that support building supportive relationships, for example, rules allowing students to help each other.

The game design in the present study encourages competition more than collaboration. It is visible in the frequency of interactions; most S2S interactions are about peer assessment. In comparison, the instances of students helping each other are fewer. Also, helping in this context is not the same as collaborating. It shows how technology design affects social interactions. Therefore, technology design should be attentive to what kind of interactions we want to encourage in the classroom and towards what goals (such as disciplinary learning, identity work, and community building).

Implications for learning scientists and education researchers

Our observations support that learning is simultaneously cognitive, affective, and social. There is a need for further research into *how* these aspects are entangled in the context of instructional games.

A shared memory space in the classroom can open an extra channel for student interactions. Verbal interactions have limitations; many students can not speak simultaneously, and verbal utterances may not always be accessed later. Our study and others (Stahl, 2006) have shown that having classroom interactions accessible is beneficial; students use them for referencing while discussing. For example, a diagram drawn on a blackboard is at least visually available for everyone in the class. Students can point to diagram elements while asking questions or arguing. A blackboard is also a shared memory space with limited access and memory. On a blackboard, not all students can create representations simultaneously, and there is a limit to how many representations can be created without easing previous ones. Digital shared memory space can help address this problem, provide simultaneous access to many students, and support students in having greater control over creating representations. However, our findings also show that classroom norms interweave with the design of the instructional game in how learning and interactions emerge in the classroom. This suggests the need for more ecologically situated research on instructional games rather than clinical studies that may not engender such entanglements by design.

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