Role of Shared Memory Space In Learning In Computer Supported Classroom

A Thesis

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by

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DECLARATION

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature and acknowledgment of collaborative research and discussions.

The work was done under the guidance of Professor Ayush Gupta and Nagarjuna G. at the Tata Institute of Fundamental Research, Mumbai.

Rafikh Rashid Shaikh

In my capacity as supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

Ayush Gupta

Nagarjuna G.

26 January 2024

Tata Institute Of Fundamental Research

Abstract

Role of Shared Memory Space In Learning In Computer Supported Classroom

by Rafikh Rashid Shaikh

Under Supervision of

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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? I used the case study method for this study, which was conducted in a village school with primary school students. Fifteen students in grades 3 and 4 participated in the study. 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 a co-located setting. In this study, interns working at Homi Bhabha Centre for Science Education and grade 4 students (n= 45) from a semi-urban school participated.

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. A total of 45 students in grade 4 participated in the study. I used the case study method and collected both qualitative and quantitative data. Classroom sessions were video recorded, computer logs were collected, and field notes were taken. Focus group discussions 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, support disciplinary learning and facilitate researchers to study social and emotional variables.

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Lastly, I would like to express my most profound appreciation to all those individuals who have contributed to this thesis in any way but whose names may have been inadvertently omitted. Your contributions have not gone unnoticed, and I am sincerely grateful for your support.

Again, Thank you for your invaluable contributions and unwavering support throughout this research endeavour.

DEDICATION

Dedicated to my friends (in alphabetical order):
Atikh, Harita, Nitin and Sachin!

And my grandmother Hamidabi.

List of Publications

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

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

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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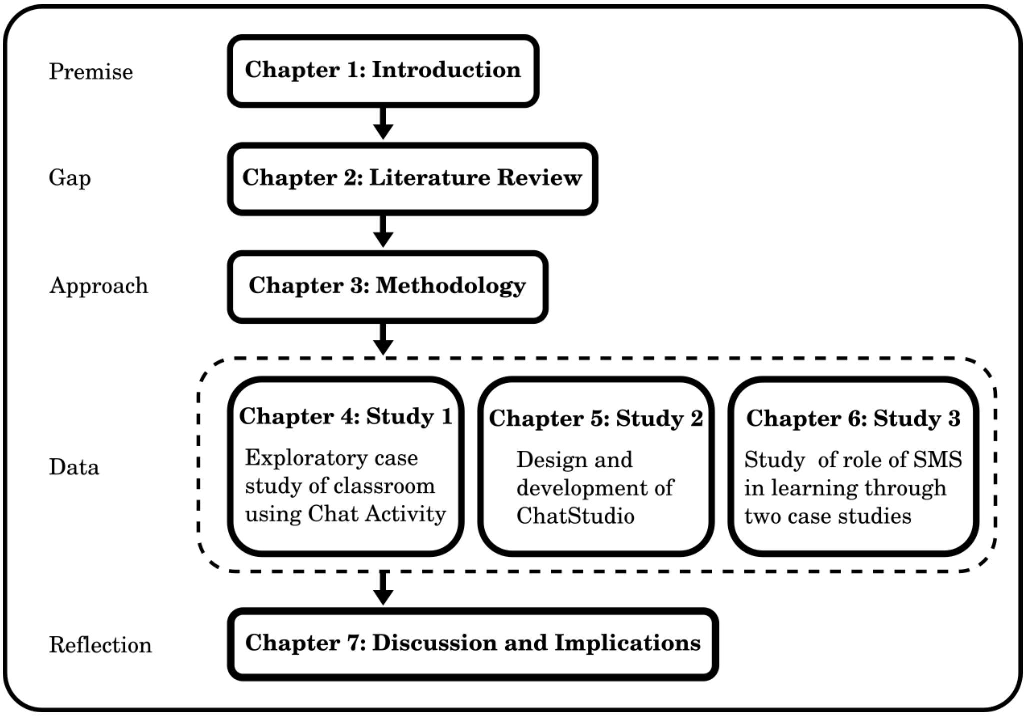
Graphical Overview of the Thesis



Organization of the chapters

Operational definitions of terms used in the thesis:

Term	Meaning
Case study	According to Yin (2003), a case study is a qualitative research method where the researcher deeply investigates a specific system or multiple such systems over time. This investigation involves collecting detailed data from various sources. A case study is an in-depth exploration of real-world phenomena, especially effective in answering 'how' and 'why' questions.
Cognitive load	Cognitive load refers to the mental effort required to process information.
Cognitive offloading	Cognitive offloading refers to the process of using technology

	to reduce the cognitive load on students by transferring certain cognitive tasks to the computer system.
Classroom norms	Classroom norms refer to the expected behaviours and standards of conduct that students are expected to follow in a classroom environment (Cobb et al., 2010; Yackel et al., 1991).
Focused group discussion	A focus group is a conversation guided by a moderator involving a limited number of participants, aiming to explore the participants' experiences, viewpoints, and/or opinions.
Student engagement	Engagement has three aspects- behavioral, affective and cognitive. This thesis focuses on the behavioural aspect of student engagement. Here "engagement" pertains explicitly to students' active utilization of a particular computer application without necessarily implying a deeper involvement in the subject matter or discipline.
Peer assessment	Peer assessment refers to the practice of students evaluating, discussing and providing feedback on their peers' work, achievements, or contributions in an educational setting where technology is utilized and elements of gamification are incorporated to enhance the learning experience.
Activity	In XO laptops, an activity refers to a computer application or program.
Setting	A setting refers to a specific classroom condition, such as a classroom with a shared screen (CSG setting).
Session	A session refers to a session of a game-play by the students in the classroom.
Segment	A segment is a portion of a video or audio recording selected for a specific purpose, such as showcasing peer assessment.
Episode	Episodes are events/incidents that form or are part of a narrative.

Chapter 1. Introduction

The thesis revolves around the concept of a shared memory space (SMS), which enables simultaneous access to representations and their manipulation in a digital environment. Across the seven chapters, I delve into various topics, including the poor quality of social interactions in Indian classrooms, an extensive review of the literature on the use of networked computers in learning environments, and the function of SMS in co-located settings. Additionally, I discuss the design and development of a learning application, the role of SMS in learning, and three empirical studies investigating the potential of a chat application in facilitating mathematics learning. The findings from these studies indicate that SMS has the potential to enhance social connections in classrooms and positively impact learning outcomes.

In this chapter, I provide a brief overview of social interactions in Indian classrooms, highlighting its predominantly teacher-centric approach and limited opportunities for peer contact in the classroom. I draw attention to recent research conducted by UNESCO, which reveals that only 24% of instructional time is dedicated to student-centred activities. While the educational system considers social interactions as potential obstacles to learning, it is widely recognized that such interactions are crucial for effective learning outcomes. Thus, this thesis focuses on addressing this issue by exploring the use of networked computers to enhance social interactions.

1.1 Background and Origin of Research Problem

This thesis explores the role of networked computers in supporting social interactions in primary schools. My journey towards this research topic began with a simple but impactful experience. Soon after joining Homi Bhabha Centre for Science Education as a graduate student, I visited a primary school in a small tribal village (less than 100 houses) where the Gnowledge lab studied the use of computers in teaching and learning at the primary school level. In this unique school (I share further details about the school in Chapters 3 and 4), every student had a particular laptop provided by the One Laptop per Child (OLPC) foundation. What made this school special was that all four grades (from 1st to 4th) shared a single classroom, and one teacher taught all subjects to everyone. The teacher encouraged students to learn from each other, often asking older siblings or friends to help teach younger students. This was possible because students from different grades sat together.

This visit made me realise the importance of peer interactions in learning. It reminded me of my school days in a similar setting, where all four grades shared one classroom, and one teacher taught all subjects. Having my older sisters in the same class helped me a lot. Their presence was empowering and encouraging.

These experiences led me to ponder the significance of social interactions in the classroom and how they influence learning. However, what I saw in the village school mentioned above is not representative of the schools in India. I have visited many schools in India and read literature focusing on the nature of interactions in schools in India and other countries. In the following few sections, I first explain patterns of interactions in classrooms, and then I present a specific pattern called Initiation-Response-Evaluation (IRE) (Mehan, 1979). I use a vignette from a classroom in India to illustrate the IRE pattern. I am not scientifically analysing the vignette I am presenting (I present a systematic analysis of a few different cases in later chapters); instead, I am using it to draw readers' attention to the nature of social interactions and highlight the need for supporting social interactions in the classroom. After the vignette, I present some studies from India that show the prevalence of the IRE pattern in Indian classrooms.

1.2 The IRE Pattern of Classroom Interactions[1]

While classrooms vary across countries, schools as social institutions are nearly universal. By focusing on classrooms where teachers teach varying numbers of students, we can identify similarities and differences in classroom interactions worldwide. One of the most prevalent interaction patterns observed in classrooms globally is the IRE pattern (Initiation-Response-Evaluation)(Mehan, 1979). In this sequence, the teacher initiates the interaction with a

[1]This section is published in: 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.

question, students respond, and the teacher provides feedback. Mehan originally identified this sequence and referred to it as IRF (Initiation-Response-Follow-up). Using conversation analysis, researchers demonstrated that in teacher-fronted classrooms, only the teacher has the power to control the flow of conversation. Students must wait for their turn to speak, but they do possess resources such as raising a hand, addressing the teacher as 'sir' or 'miss,' or using gaze and body posture to indicate their desire to speak. However, the power dynamic is tilted towards the teacher, who decides which student can speak in the classroom. When a teacher asks group questions, multiple students may raise their hands, but *only one student can participate at a time*. While students do have some agency within IRE-type routines, their active participation and autonomous interactions in the classroom are limited by the teacher's tight control. The power tilt towards the teacher hampers students' active engagement and independent interactions in the classroom.

1.2.1 Classroom Interactions: A Vignette

The following vignette is drawn from a video of a classroom observed in November 2017 at a government high school near Jaipur, Rajasthan. This observation is an illustrative example to shed light on typical classroom dynamics prevalent in Indian educational settings. The lesson, delivered in Hindi, featured a male teacher instructing a high school class.

In this setting, the teacher stood near the blackboard while students occupied benches arranged in pairs. The classroom was crowded, accommodating approximately 45 students, with girls seated on the left side and boys on the right. Each student had their textbook and notebook placed in front of them. The teacher listed the planets' names on the blackboard in the solar system.

The interaction unfolded as follows (the video was transcribed in Hindi and then translated from Hindi to English by me):

Teacher: The earth has life. There are plants, animals, insects, etc. Have you seen it?

Students (in chorus): Yes... Yes.

Teacher: Have you ever thought if there could be life on other planets?

Few students: Yes.

Teacher: Have you seen it? Have you heard about it?

Few students: Yes.

A Male student: Sir, the planet Mars.

Teacher: No, life is not found on Mars. We have just reached Mars.

A male student: Yes.

Teacher: See, we have just reached Mars. In 2008, India reached the Moon. We read about it. In 1975, we launched a satellite. Which one? The Aryabhata.

Students (in chorus): Yes.

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Teacher: I have a question. Who will answer?

(The teacher initially glanced at the boys' benches, then shifted his gaze towards the girls' side. He pointed to a female student and asked:)

Teacher: Surbhi, can you tell us which is the giant planet?

(Surbhi stood up)

Teacher: Biggest one?

Student (Surbhi): Jupiter.

Teacher: Jupiter.

(The teacher gestured for Surbhi to sit down, and she complied.)

In this example, the teacher predominantly assumed the role of the primary speaker (in the above example, 9 out of 16 utterances were made by the teacher) while students participated when explicitly prompted (see lines 1-2, 3-4, 5-6, and 13-19). Peer-to-peer interaction among students was minimal (the interaction patters is teacher-student-teacher). Notably, if the teacher observed students engaging in conversations amongst themselves, he promptly redirected their attention to his lecture. The teacher-student interaction adhered to a distinct pattern, often initiated by the teacher posing a question and the students responding in unison with a "yes." The teacher emphasized specific words in sentences, and students echoed these words. Occasionally, the teacher directed questions at specific students, acknowledging their responses and providing explanations as necessary. This pattern aligns with the above-mentioned IRE pattern (for example, see lines 13 to 20) (Mehan, 1979).

It is important to note that this example is representative of the prevalent classroom interaction patterns observed in Indian classrooms, with some variations. In the subsequent section, I will present studies from India that corroborate and expand upon these patterns of classroom interactions.

1.2.2 Prevalence of IRE Pattern in Indian Classroom

According to a report published by UNESCO in 2021, classroom activities in India are primarily teacher-centric, with 41% of instructional time allocated to such activities. In contrast, student-centric activities account for only 24% of the time (Sarangapani et al., 2021). In Indian classrooms, students rarely have the opportunity to speak or interact with their peers. While they can occasionally ask questions to the teacher, talking to fellow students is discouraged. The same UNESCO report (Sarangapani et al., 2021) reveals that 60% of classroom time is devoted to activities such as teachers writing on the blackboard, students copying from textbooks, and students repeating what the teacher says. Only 30% of classroom time involves activities like teachers asking questions, students writing on the blackboard, teachers utilising local context and language, and students working in groups (Sarangapani et al., 2021). Interactions among students are considered disruptive to learning since it is seen as an individual pursuit (Sarangapani, 2003b). Conversations with peers also contradict the prevailing culture of discipline in Indian classrooms (Sarangapani, 2003b). Indian teachers idealise students who remain silent, obediently follow instructions, and show respect for the teacher. This belief is rooted in the traditional Indian concept of Guru-Shishya (Sarangapani, 2003b, 2003a), where the teacher holds a central position, acting as the sole authority on knowledge and the go-to person for any academic or other issues.

1.3 Nature of learning and role of classroom interactions

Modern learning theories emphasise the importance of social interactions in the learning process. According to sociocultural theory, learning is fundamentally a social phenomenon. All learning instances, whether through group activities or individual engagement with materials, possess a crucial social element. Vygotsky (1978) argues that even when a student learns alone by interacting with materials, the activity is social because the learner employs specific tools that are products of social and cultural processes. Language is one such tool that facilitates communication and shapes our thoughts. Therefore, even when students learn independently, they use inherently social language. Language serves as an example of sociocultural tools, as learners employ various other tools in the learning process.

Vygotsky also explains how interactions with others facilitate learning through his Zone of Proximal Development (ZPD) concept. He highlights how interactions with a knowledgeable individual, be it an elder or a peer with more knowledge on the subject, can help a learner acquire new concepts and skills. With the assistance of knowledgeable others, a learner can progress from their current conceptual level to the next. The learner's ability to independently perform a task determines their current level. In contrast, the level they can reach is determined by what they can achieve with the help of knowledgeable others. A learner cannot learn everything with the aid of others, but they can acquire knowledge within proximity to their current level. For instance, a primary school student may be able to add numbers involving three digits independently but struggle with carrying over in three-digit addition. By supporting the learner through questions, examples, materials, or problem restructuring instead of directly providing answers, a knowledgeable other (a teacher or a fellow student) can successfully enable the learner to perform three-digit addition with carry-overs.Thus, a classroom environment tightly controlled by the teacher, where peer interactions are discouraged, is not conducive to effective learning. Interactive classrooms that encourage student participation are beneficial for learning, as evidenced by various studies (Baepler et al., 2014; Kay & LeSage, 2009; Prince, 2004; VanLehn, 2011). Additionally, active student participation in classroom activities can lead to a change in students positioning in a classroom, from novice to competent actor. For example, a longitudinal study by Cekaite

(2007) observed a 7-year-old Kurdish girl in a Swedish classroom transforming from a shy and silent child to a confident and skilled individual due to successful participation in immersive classroom activities. In the Vygotskian perspective, learning is an active process, and classroom interactions play a vital role in facilitating it (Chaiklin, 2003). Cekaite (2007) introduces the concept of "interactional repertoires," which encompass semiotic, multimodal, and embodied resources that learners utilise to draw upon shared knowledge in the classroom. Recognising the importance of social interactions in classrooms, various methods and approaches have been designed and implemented to foster interactivity. In the following section, I will discuss some of these efforts.

1.4 Efforts to make classrooms interactive

Numerous efforts have been made, studied, and reported to enhance interactivity in classrooms. These efforts range from pedagogical reforms to the utilisation of digital technologies. Some notable approaches are: a) a framework called ambitious science teaching (Windschitl et al., 2020), b) Educational infrastructure to support argumentation and debate in the classroom (Bell, 2013), c) 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), d) Use of "Exploratory Talk" and "Thinking Together" strategies that enable students to use talk more effectively in collaborative reasoning in science and mathematics classrooms (Mercer, 1994, 2008, 2010; Mercer & Dawes, 2014; Mercer & Howe, 2012; Mercer & Sams, 2006) and e) Use of digital technologies both stand-alone and networked (Baumöl & Bockshecker, 2017; Es-Sajjade & Paas, 2020; Jewitt, 2005; Stahl, 2009, 2023). Networked computers, specifically Web 2.0, have transformed interactions in the classroom, allowing more social interactions. Vygotsky's concept of more knowledgeable others (MKO) has expanded with networked computers, along with peers and teachers; it includes adaptive computer programs and peers from remote locations (Cicconi, 2014). The present thesis focuses on the last approach, i.e. the use of networked computers to support classroom interactions. In the next section, I define the research problem and list the research questions this thesis tried to answer.

1.4.1 Defining the research problem

In the last few decades, the use of networked computers to support classroom interactions has been studied (a brief overview of these studies is in Chapter 2). My exploration started with broad questions, and my focus narrowed down during the thesis. The first question came from observations made during the field visits and a request by the teacher. I noticed that students often connected via local mesh networks with each other in and out of the school and used a simple, instant messaging application (called Chat Activity, native to XO laptop) to interact. The teacher asked for help finding an application to help students learn arithmetic skills. I thought we could leverage the Chat Activity itself for learning arithmetic skills. I also thought this could be a good opportunity to study game-based learning. This led to the design of our Study 1 (presented in Chapter 4), where the research questions were:

1. Can an instant messaging environment (Chat activity) be used to teach arithmetic skills?
2. If yes, how does learning happen, and what features help in learning?

Based on the insights from Study 1, I narrowed my focus to a specific feature enabled by networked computers. Networked computers make sharing of representations in real-time possible. Specifically, some applications allow multi-user access to representations and their manipulation in a digital space. Application/services such as Google Docs, a wiki or a chat environment, a multiplayer game or a virtual whiteboard are such spaces. In literature, the terms such as 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. In this thesis, I am focusing on shared digital spaces, which I will refer to as shared memory space (SMS). Henceforth, I use this term to talk about my work. In a sociotechnical 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). In Study 2, I designed a game-based learning environment that integrates Chat Activity with Shared Memory Space. We called it ChatStudio. In study 3, we did a comparative case study of two settings, one with access to the shared screen (ChatStudioGroup, CSG) and another without (ChatStudioSelf, CSS):

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?

I will describe these studies in detail in the following chapters.

1.5 Structure of the thesis

The thesis comprises of seven chapters, although the progression of my understanding of the topic, research questions, and analytical methods has undergone multiple iterations. Figure 1 is an overview of the research trajectory. From the initial research proposal to the writing of the thesis, my perspectives on learning, the role of technology, peer interactions, instructional approaches, the teacher's role, theoretical positioning, and methodological issues have undergone significant changes. These changes were influenced by graduate courses at HBCSE and other institutes, interactions with peers and faculty, participation in conferences and seminars, reading papers and books, working at CETE in Tata Institute of Social Sciences Mumbai, and engaging with students and teachers throughout India. While the thesis presents a linear narrative, it reflects my current understanding based on past events.

Chapter 1 sets the foundation by addressing the problem of inadequate interactions in classrooms in India and other countries. I discuss various solutions and explain why I chose to investigate the use of networked computers and games to enhance classroom interactivity.

Chapter 2 critically reviews studies that have utilized computers in educational settings. It includes a brief historical overview of computer-supported learning, highlighting its origins and current status. Furthermore, I present findings from studies that have explored the role of networked computers in mediating social interactions and promoting learning. I also point to the areas of concern for future research mentioned in the existing literature and discuss previous efforts. This chapter underscores the necessity of the present study and situates it within the broader context of computer-supported collaborative learning (CSCL) literature.

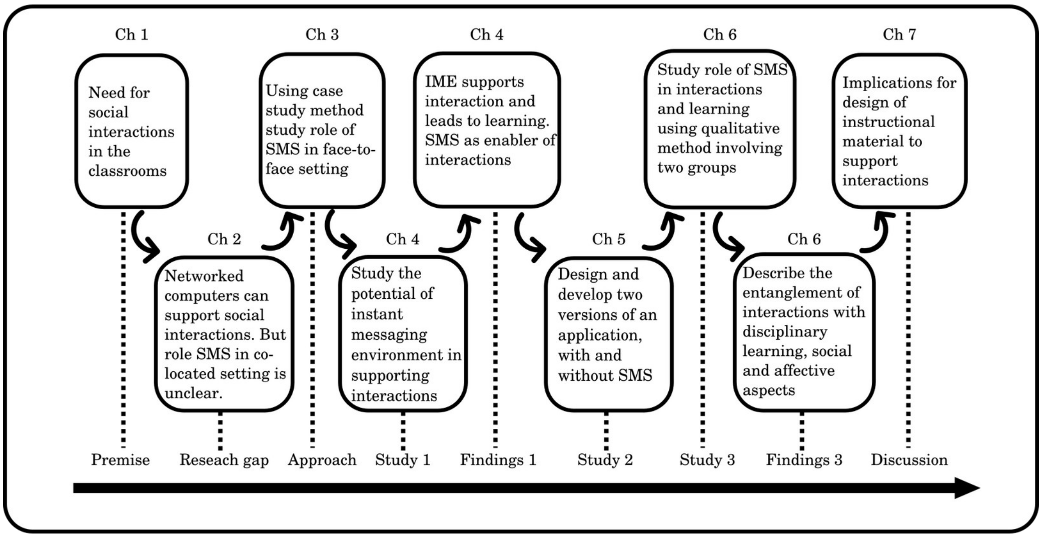

Figure 1: *Overview of research trajectory*

Chapter 3 begins by describing the methodologies commonly employed in the CSCL field to study collaborative knowledge construction. I then outline the specific methods adopted for my studies, providing the rationale behind their selection. Lastly, I provide details of each study's data collection and analysis processes.

Chapter 4 focuses on Study 1, conducted with students from a small village. The aim of this study was to investigate whether an instant messaging environment could facilitate social interactions and promote the learning of arithmetic skills.

Chapter 5 introduces Study 2, where I designed an application called ChatStudio. Reflecting on the insights gained from Study 1, I explain the decision to investigate the role of shared screens in learning. To facilitate this study, two versions of the application were created. I discuss the design and development process of ChatStudio, along with the design principles, challenges faced, and strategies employed to address these challenges.

Chapter 6 presents the findings from Study 3, which systematically explored the role of the shared screen (Shared Memory Space) in constructing knowledge, shaping status, and evoking emotions.

Finally, Chapter 7 synthesizes the findings from all three studies and relates them to the works of other researchers. I explain how Shared Memory Space supports and facilitates social interactions, leading to learning and the construction of status and emotions. Furthermore, I discuss the implications of this study's findings for the use of digital games in mathematics instruction, the design of digital learning environments, and education in general. Lastly, I acknowledge the limitations of the studies and outline plans for future research.

Throughout the thesis, I reuse some text/figures/tables published in journals 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. Literature Review

In this chapter, I embark on a comprehensive literature review to understand the role of computers in the learning process. The effectiveness of computer-based learning applications depends on the underlying theories of learning employed by designers. Drawing from the sociocultural theory of learning, I view computers as mediators that provide a space for learners to interact and collaborate. The shared memory space (SMS) serves as a context for social interactions, enhancing learners' visual awareness of problems and facilitating productive conversations. While social interactions mediated through SMS can yield various socio-affective outcomes, further research is needed to deepen our understanding of these interactions. Furthermore, I explore the affordances of games integrated with SMS, particularly regarding motivation, competition, collaboration, and their impact on the construction of status and emotions.

As mentioned in the previous chapter, one of the approaches to creating interactive classrooms is the utilization of networked computers. However, computers made their way into educational settings long before networked computers became commonplace. In the section below, I will provide a brief overview of the historical progression of computers in educational spaces.

2.1 History of Computers in Education

Educators and researchers have adopted various approaches to incorporating computers into education. Koschmann (1996) identified four distinct approaches based on the underlying theories and their practical applications in the field. These approaches include: 1) computer-assisted instruction, 2) intelligent tutoring systems, 3) LOGO as Latin, and 4) Computer Supported Collaborative Learning (CSCL). Here, when Koschmann (1996) uses the term ‘ LOGO-as-Latin’, he means studying Logo programming language, likened to studying Latin, provides insights into cultural and educational shifts, revealing the impact of computers on learning and cognition.

2.1.1 *Computer-assisted instruction*

Computer-assisted instruction emerged in the 1960s during the prevalence of the behaviourist learning theory. Learning was primarily viewed as the memorisation of facts. Computers were employed to present information to students in a logical manner, facilitating memorization. This approach continues to be popular among commercial educational package providers.

2.1.2 *Intelligent tutoring system*

In the 1970s, there was a shift from behaviourist theory to cognitivist philosophy. The intelligent tutoring system was born out of this cognitivist philosophy and Artificial Intelligence (AI), which focused on learning through mental models and representations. Intelligent tutoring systems incorporated computer models of students' understanding and responded to their errors based on these models and typical errors identified by the system.

2.1.3 *LOGO as Latin*

Papert (1980) and his colleagues formulated the LOGO-as-Latin approach in the 1980s. The Logo-as-Latin research theme refers to a cultural-practice approach applied to educational technology, specifically the Logo programming language. Here the comparison between Latin and LOGO is made to illustrate that just as Latin is not just a language but a cultural practice, LOGO is not just a programming language but a cultural practice. This approach focuses on the cultural contexts in which the technology is used rather than just the technology itself. By understanding the culture in which the technology is used, researchers can gain a fresh perspective on how it is learned and used. This approach was grounded in the constructivist theory of learning, which posits that children construct their knowledge. Papert argued that learning could not occur without engaging learners in activities that involve tangible outcomes, such as creating toys or working with operations that lead to visible effects (Papert, 1980). Papert referred to this approach as constructionism. He and his team at MIT developed computer-based activities, such as LOGO, to provide learners with construction opportunities in a tangible learning context, particularly for grasping abstract concepts like mathematical constructions.

Numerous empirical studies have been conducted to validate Papert's approach. For instance, Harel (1991) successfully employed LOGO to facilitate fraction learning, while Noss (1987) explored the potential of LOGO in helping children understand geometric concepts such as length and angle, finding that the LOGO programming environment enhanced the acquisition of these concepts, particularly for girls. Yelland (1994) conducted a case study with six students and observed that girls' performance exhibited higher accuracy in terms of error reduction and task completion time, albeit with a higher number of moves made. Hughes (1986) demonstrated how LOGO can be adapted for young children, significantly impacting their mathematical understanding. Suomala (1999) conducted an empirical study to analyse Seymour Papert's theoretical ideas about constructionism and LOGO within a real problem-solving context. This study involved 198 students from three primary schools and was conducted in two parts: the first part examined LOGO's influence on students' performance on a test, while the second part studied the problem-solving process of the LOGO group. Additionally, Ratcliff and Anderson (2011) conducted a study with nine 4th-grade children with mild disabilities, concluding that programming with LOGO, particularly when faced with challenges, could be particularly beneficial for students with mild disabilities. Papadopoulos and Tegos (2012) conducted a study evaluating various methods of teaching programming to novices and found that microworlds like LOGO and Scratch (a derivative of LOGO) can be employed to teach programming to beginners. Furthermore, Yeh (2010) conducted a study with primary school students using VRLE (3D LOGO), wherein the task involved envisioning rotation in a 3D world. The study found that young students struggled to perceive and comprehend the nature of 3D rotation, but VRLE provided them with experiences rarely encountered in real life, aiding in their understanding of 3D manipulations and mental rotations. LOGO has been very popular. There have been several hundred variants of LOGO created by different people.

Papert's constructionism represents a fusion of Piaget's constructivist theory from developmental psychology and the possibilities offered by technology. It advocates for science and mathematics education based on activities that enable students to construct tangible entities, rather than simply acquiring knowledge and facts devoid of context for immediate use and comprehension (Papert, 1980). Technology, including LOGO, was utilized to create an environment in which children could engage in construction activities. Subsequently, many researchers have endeavoured to investigate the use of technology in education. In recent times, applications like Scratch[2], which employ visual block programming languages, have been employed to facilitate the learning of sciences, mathematics and social sciences by children. Specifically Scratch has been used in developing 'Computational Thinking' (Ersozlu et al., 2023; Troiano et al., 2019), motivating students to learn coding and robotic (Attila & Szilvia, 2022), solving multi-step equations in mathematics at school level (Chiang & Qin, 2018).

One notable development from the MIT labs is the One Laptop Per Child (OLPC) project, which provides a comprehensive set of construction activities through the implementation of a Sugar Learning Platform on a laptop (Kane et al., 2012). A core feature of this project is the avoidance of content delivery via computers. Content delivery has been the prevailing method of utilizing computers for education within the traditional computer-aided instruction (instructionist) framework. In contrast, the constructionist framework emphasizes the active production of content by students, rather than passive consumption (Kane et al., 2012). Thus, this educational philosophy is founded upon the constructivist principle that education should be child-centric, with children acting as active agents in knowledge construction. The laptops employed in this study were sourced from the OLPC project, and the applications utilized followed the LOGO as Latin approach. Further details regarding the OLPC laptops and their associated applications will be discussed in subsequent chapters.

2.1.4 Computer supported collaborative learning (CSCL)

In the 1990s, researchers and educators began to explore the potential of using computers, particularly networked computers connected via the internet or local networks, to facilitate collaborative learning in small groups or communities. This approach was based on the

[2]https://scratch.mit.edu/

sociocultural theory, which highlights the significance of social interactions in knowledge construction.

Distinguishing itself from previous approaches, computer-supported collaborative learning did not position the computer as an intelligent tutor or assistant. Instead, the computer played a secondary role, serving as a medium to bring students together (Stahl, 2013a). In this approach, students primarily learn through interactions with their peers, with the computer acting as a facilitator of these interactions across temporal and spatial boundaries. This approach differed from the LOGO as Latin approach as it placed greater emphasis on social interactions and artefacts. In the CSCL approach, the computer environment provides pedagogical support and scaffolding for collaborative learning, but its purpose is not to replace human or group interaction; rather, it is meant to support and enhance it (Stahl et al., 2006a; Stahl, 2023).

While these approaches emerged successively, many of them remained popular for extended periods or are still in use today. Several approaches coexist and are currently employed in educational settings. For instance, Papert's renowned LOGO as Latin approach and CSCL are currently the two most popular approaches in computer-aided learning. While Koschmann (1996) characterization is not exhaustive, it provides an overview of computer-aided learning from a broad perspective.

Although the laptops and applications utilized in this study followed the LOGO as Latin approach, our study was situated within the CSCL framework. To provide readers with a better understanding of the CSCL approach, I will elucidate its principles in detail in the subsequent section.

Summary of 2.1: Examining the historical evolution of computers in education, this section focuses on key approaches such as Computer-Assisted Instruction, Intelligent Tutoring Systems, LOGO as Latin, and Computer-Supported Collaborative Learning (CSCL). It highlights the cultural-practice perspective of LOGO-as-Latin and underscores the need for *future research to explore the cultural implications of emerging educational technologies and assess the continued relevance of historical approaches in contemporary contexts.*

2.2 A Brief Overview of CSCL

In 1989, a NATO-sponsored workshop on "computer-supported collaborative learning" was held in Maratea, Italy, widely recognized as the seminal event that formalized the field of CSCL (Stahl et al., 2006a). Prior to this workshop, several significant projects served as precursors to the development of CSCL. One such project was the ENFI project at Gallaudet University, where students with hearing impairment used a networked computer-supported application, similar to a chat platform, to write compositions collaboratively. Another influential project, CSILE (Computer Supported Intentional Learning Environment), conducted by Bereiter and Scardamalia at the University of Toronto, explored learning in "knowledge-building communities" as opposed to traditional classroom settings (Scardamalia & Bereiter, 1996; Stahl et al., 2006a). Additionally, the Fifth Dimension (5thD) project at Rockefeller University investigated the use of computer-based activities to enhance students' reading and problem-solving skills (Cole, 1996; Stahl et al., 2006a).

Following the Maratea workshop, the field of CSCL experienced rapid growth, with specialized literature documenting research and theoretical advancements. Much of this work appeared in edited proceedings of CSCL conferences and select journals. Notably, the first CSCL conference took place in 1995 at Indiana University, establishing a biennial tradition that continues to this day. As CSCL matured, it evolved as a distinct branch within the broader field of learning sciences, addressing collaborative learning supported by computer technology.

CSCL emerged as a reaction to the limitations of computer software that confined students to isolated learning experiences. It sought to transform education by emphasizing collaborative interactions, knowledge construction, and the role of the teacher as a facilitator. Unlike the narrow definition of e-learning or online learning, which often involves content delivery to isolated learners via the Internet, CSCL recognizes the vital importance of human teachers in the learning process. CSCL regards the teacher's involvement as integral, requiring their active participation and effort to foster effective collaborative learning environments (Cress et al., 2021; Stahl, 2023)

Over the years, CSCL has expanded its scope and influence. It has embraced diverse educational contexts, from traditional classroom settings to online environments and hybrid learning spaces (Stahl, 2023). Technology has played a crucial role in shaping CSCL, with a variety of collaborative tools and platforms enabling learners to engage in shared activities, knowledge creation, and problem-solving. Moreover, advancements in artificial intelligence and data analytics have opened up new avenues for studying and supporting collaborative learning processes.

CSCL continues to evolve today, driven by ongoing research, technological advancements, and pedagogical innovations (Cress et al., 2021; Hmelo-Silver & Jeong, 2021; Stahl, 2023). The field explores various dimensions of collaboration, such as social interactions, knowledge building, shared cognition, and collective problem-solving. Researchers in CSCL investigate the design of collaborative learning environments, the impact of technology on collaboration, the role of social and cultural factors in collaborative interactions, and the effective integration of CSCL into educational practices.

CSCL research and practice have also extended beyond formal education to informal learning settings, professional development, and lifelong learning contexts. With the advent of online platforms, social media, and virtual communities, CSCL has found new avenues to foster collaboration and knowledge sharing beyond the confines of physical classrooms (Stahl, 2023).

CSCL has come a long way since its inception in the late 1980s. From the early projects that paved the way for collaborative learning supported by computers to the emergence of specialized conferences and journals, the field has evolved into a multidisciplinary domain that investigates the intricacies of collaborative learning, technology, and pedagogy. As CSCL continues to advance, it holds the potential to reshape education by promoting active engagement, knowledge co-construction, and the development of crucial collaborative skills necessary.

As mentioned in Chapter 1, this thesis project focuses on using networked computers, specifically shared memory space, in co-located classrooms. In the next section, I review the studies investigating networked computers' use in co-located classrooms.

Summary of 2.2: Tracing the inception and growth of Computer-Supported Collaborative Learning (CSCL) since the 1989 NATO workshop, this section emphasizes collaborative interactions, technological impact, and ongoing research in diverse educational contexts. Future studies could address integration challenges and assess the effectiveness of CSCL in evolving educational landscapes.

2.2.1.1 CSCL in a co-located classroom

Piaget and Vygotsky had slightly different views on the role and nature of social interactions in learning. For Piaget, interactions with peers are more valuable than with adults. He believed interactions with adults are unequal and asymmetrical and do not have the reciprocity required for learning. Whereas for Vygotsky, interactions with more skilled others are essential for learning. The more skilled others can be peers or adults. Vygotsky saw the interactions with more skilled others as instruments that help children get encultured in the intellectual tools of society (Tudge & Rogoff, 1999). Initiating and sustaining interactions among students is not easy to achieve; it needs careful planning, selection, design, and use of proper technology (Stahl, 2010). Various strategies are used to stimulate and sustain interaction inside and outside the classroom. Use of networked computers in one such strategy. It has led to the emergence of area research called Computer Supported Collaborative Learning (CSCL). Even though CSCL broadly refers to online settings, face-to-face (co-located) collaboration in computer-supported classrooms is also a concern of the community (Stahl, 2023).

Summary of 2.2.1.1: Navigating Piaget and Vygotsky's perspectives on social interactions in co-located classrooms, this section emphasizes the challenges of fostering student *interactions and the role of careful planning and technology use. It highlights the emergence of Computer Supported Collaborative Learning (CSCL) in face-to-face settings, prompting future research to optimize strategies for effective co-located CSCL.*

2.2.1.2 Shared Memory Space (virtual)[3]

In Chapter 1, I have introduced the term Shared Memory Space. To ensure that the idea of SMS is clear, I am reintroducing it here briefly. SMS refers to a feature enabled by networked computers, allowing users to share and manipulate digital content in real-time through various collaborative applications and services. This feature facilitates simultaneous access and collaboration in tasks such as document editing, wiki or chat environments, multiplayer games, and virtual whiteboards. In academic literature, different terms like shared activity space and shared workspace have been used to describe these collaborative platforms. However, I am using the term shared memory space (SMS) in this thesis. SMS expands the memory space of individuals within a sociotechnical system, like a computer-aided classroom, by providing a digital window where participants can jointly create, view, and manipulate representations. In the following paragraphs, I review studies investigating SMS in various learning settings.

Learning in computer-supported spaces, where SMS is involved, has been studied by many researchers—starting with Roschelle and 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

[3]This section is published in: 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.

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 and Toker (2019) examined the development of trust among students. They compared the development of trust in two 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 computer-mediated communication (CMC) setting, it surpassed the co-located (face-to-face) setting in the long run.

In the Indian context, there were limited research studies in which the setting was co-located, and the learning application had SMS. One such study was done by Kapur and Kinzer (2007), who investigated the influence of problem type in synchronous-collaborative learning. Students of grade 11 sat in groups of three and used a chat application to communicate. Even though they were sitting in the same room, they only had to communicate through a chat application; face-to-face communication was avoided. Participants were also not aware of group members' identities. They found that the structure of the problem (Ill vs Well structured) impacted students' interactional activity. Groups solving ill-structured problems engaged significantly more in problem-centred activity. The same group also showed a more equitable level of participation by all members in the activity. Another study by Lomas et al. (2011) at the primary school level investigated the constraints and affordances of a digital game as a tool for learning. They found that the social game played using an 8-bit computer was successful in invoking participation and helping children learn English words. It is not easy to find studies from India that had learning applications with SMS. Overall, CSCL in a co-located setting is less explored in the Indian context.

Summary of 2.2.1.2: Reintroducing Shared Memory Space (SMS), a networked computer feature enabling real-time collaboration, this section discusses SMS's effectiveness in enhancing social engagement, mediating conversations, and increasing problem context awareness. Future research is needed to understand SMS's impact in co-located learning settings, especially in diverse educational environments.

2.2.1.3 Games and shared memory space[4]

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 social game (D. Lomas et al., 2011) mentioned in the previous section can be considered an example of a game with 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). However, some studies suggested that all educational games do not motivate students to learn disciplinary subjects (Es-Sajjade & Paas, 2020). The motivational effect of educational games depends on multiple design features, e.g. vivid animations, game-play, etc. (Es-Sajjade & Paas, 2020). Educational games also provide context for learning by doing and make learning fun (Kirriemuir & McFarlane, 2004).

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).

[4]This section is published in: 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.

Competition is considered more effective in stimulating students' learning progress (Cagiltay et al., 2015), as in competitive mode, students are more likely to adopt performance-oriented goals (Lam, 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. In contrast, having both competition and collaboration elements in a game makes it better than only a competitive game in achieving learning outcomes (Clark et al., 2013).

Multiple theories are used to understand the affordances of educational games. Broadly, these approaches can be classified as socio-cultural or psychological (Ho et al., 2022). Psychological approaches tend to focus on an individual’s experience, such as feelings of connection, competence and control (Deci & Ryan, 2012; Ho et al., 2022). Socio-cultural approaches (with which our approach aligns) consider social interactions essential for learning. Here, 'play' is considered an essential activity for development (Verenikina, 2003; Vygotsky, 1977). Vygotsky's idea of the Zone of Proximal Development explains why peer interactions are essential for learning.

Summary of 2.2.1.3: Exploring the educational potential of multi-player digital games with Shared Memory Space (SMS), this section discusses how these games motivate STEM learning. It highlights the powerful motivational effects of collaborative and competitive elements and suggests combining them for enhanced learning outcomes. Future research could delve into the nuanced impact of different game design features on motivation and learning outcomes in diverse educational contexts.

2.2.1.4 Peer-assessment in CSCL

Peer assessment involves students' active engagement in assessing, discussing and evaluating each other's work (Boon, 2016). It is a formative assessment strategy used to enhance learning through student collaboration, communication and problem-solving skills (Ahmed, 2018). CSCL community has also been studying peer assessment in the CSCL environment. The community acknowledges that technology does not automatically lead to learning and peer assessment, but the learning environments must be redesigned to include peer assessment opportunities (Prins et al., 2005). Boon (2016) says peer assessment can enhance learning by promoting collaboration, effective communication, and student self-assessment. Pifarre and Cobos (2010) found that it can also support the development of metacognitive skills and increase the presence of metacognitive processes in students' learning. Hoang et al. (2022) found that students exhibit a positive attitude towards peer assessment (Chen, 2021), and the quality of assessment is better when they know that their peer assessment activities were included in the final score. Similarly, Phielix et al. (2009) found that peer assessment positively enhances group functioning and changes attitudes towards collaborative problem-solving.

Summary of 2.2.1.4: This section emphasizes peer assessment's formative role in CSCL, fostering collaboration and problem-solving. Intentional design positively influences attitudes and group functioning, suggesting a need for optimized methods and enhanced student engagement in future research.

2.2.1.5 Virtual Math Teams as an example of SMS[5]

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)" (see Figure 2). 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.

[5]This section is published in: 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.

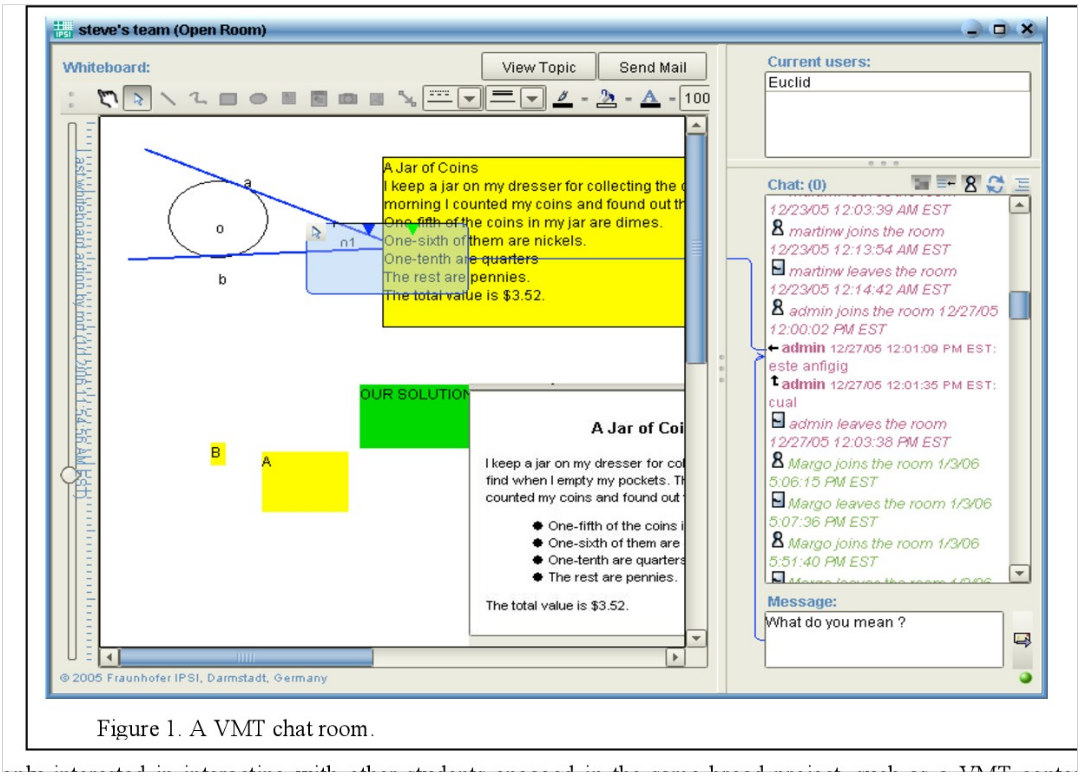

Figure 2: *Screenshot of Virtual Math Teams application (Stahl, 2009)*

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 titled ‘Studying Virtual Math Teams’ by Stahl (2009) to comprehensively understand their work with VMT.

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 mathematics 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). Perception of students' competence by teachers/mentors and learners' perception of gaining competence affects attitude and emotions. The construction of attitudes and emotions happens 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.

Summary of 2.2.1.5: Delving into the Virtual Math Teams (VMT) project within Computer-Supported Collaborative Learning (CSCL), this section emphasizes SMS's role in collaborative knowledge building. Stahl's decade-long study reveals the effectiveness of virtual groups in learning mathematics through interactive SMS interfaces, emphasizing joint-problem space co-construction and sequential representation creation. Future research could explore the intersection of SMS, collaborative learning, and emotional factors in diverse educational contexts.

2.2.1.6 Summary

The literature I presented above can be summarised as follows:

- 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 provide a space for learners to interact.
- 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.
- One of the critical affordances of the game with SMS is that it motivates students to engage in 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.

The literature review in this chapter 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 above also indicated the way forward for future research:

- Literature acknowledges that the design features of digital learning environments determine learning outcomes. However, social and affective outcomes and their connection with design features need to be studied in more detail.
- 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.

- Very few process-based accounts of digital game environments with a focus on interactions between disciplinary learning and other socio-affective aspects exist.

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 chapter outlines the methodology employed in this thesis, which involves multiple studies to investigate the role of shared memory space. Each study adopts a different approach based on the research questions. The research problem emerged from the first study, which followed an exploratory path, leading me to adopt a case study method. I examined a classroom case that used an arithmetic learning application, collecting data through interviews, classroom observations, and computer logs. The second study follows a product design approach, as I designed and developed ChatStudio—an application that underwent iterative cycles of design, development, testing, and reflection. The third study systematically investigates the role of SMS in learning by examining two contrasting classroom cases—one with and one without. The contrasting cases enable me to discern the role of SMS in generating patterns of learning and interactions.

3.1 Research methods used in CSCL

As mentioned earlier, CSCL arose as a reaction to an individualistic approach to learning and software aimed at isolated learners. In CSCL, computers were used to support multiple learners learning together, and learning was viewed as fundamentally social. It is a significant shift from viewing learning as an individualistic process (Puntambekar et al., 2011). Therefore, researchers working in the field, from the beginning, adopted research methods that capture the display of learning in group interactions. Designs like pre-and post-tests were deemed unfit as they cannot capture the learning that happens when a learner is not isolated but situated in a group. Designs like micro case studies, design-based research and mixed methods were preferred, considering their potential to capture the learning that is visible in interactions and happens in a short period of group interactions (Stahl et al., 2006b). Primarily focus on spoken and written language and non-verbal interactions in different learning contexts (Hmelo-Silver & Jeong, 2021). Methods in the CSCL have been derived from education, cognitive science, psychology, computer science, artificial intelligence, linguistics and anthropology. Various methods, such as content analysis, social network analysis, analysis of computer logs, multilevel models, visual representation of data, interaction and conversation analysis, etc., are used to study and model learning in groups (Puntambekar et al., 2011). While understanding learning, both the process and outcome of learning are studied. Learning is measured at the individual and/or group level.

3.2 Research questions

Research questions evolved during the study; exploration started with a design problem and later became my thesis's topic. As mentioned in Chapter 1, the following broad research questions guided my work:

1. Can an instant messaging environment (Chat activity) be used to teach arithmetic skills?
2. If yes, how does learning happen, and what features help in learning?
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 the first two questions in Study 1 (described in Chapter 4). Questions 3 to 5 were formulated after Study 1 as I narrowed our focus on the shared screen. During Study 3 (described in Chapter 6), questions 3, 4 and 5 evolved through an iterative process in conjunction with the analysis (Maxwell, 2012). The final refined research questions in Study 3 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?

As mentioned earlier, for study 1, I chose a small village school. Several considerations guided my choice of OLPC laptops and a small school from a tribal village. OLPC laptops (called XOs) were specifically designed for school students. Both hardware and software were released in the Creative Commons or GNU General Public Licence (GPL), which was necessary for modifying and adopting it as needed. XOs had Marathi language support as that was the medium of instruction in the school, and no internet connection was required to connect XOs. Laptops had the technology to create a local mesh network that worked in and out of the school. It played a crucial role in creating a group activity in a village without an internet connection. Students in this school have been using OLPC laptops since they were in grade 1. This meant that the students in grades 3 and 4 who participated in Study 1 had experience using laptops for 2-3 years. It allowed me to observe students' use of laptops and use the insights in designing activities later. From a research point of view, if something works in a remote village where access to resources is an issue, and challenges are plenty, it would be easier to implement it in other schools (rural and urban), considering the context-specific changes.

Whereas for Study 3,I chose a suburban school in Mumbai, India. This school was similar to the village school but had a few differences. Most of the students who participated in Study 3 were first-generation learners. The medium of instruction was Marathi, and a single teacher taught all the subjects. However, unlike the previous school, this school was located in a suburb of Mumbai. The previous school had a total of 24 students, whereas this school had 45 students in just one division of grade 4. A large classroom size was ideal for dividing them into two groups. By selecting an urban setting for the second study, I studied intervention in two different settings (rural and urban).

A review of the literature showed that the research questions I selected had not been studied sufficiently, especially at the primary level, in a face-to-face setting and in the Indian context. Most of the studies measured outcomes but did not examine the learning process and the role of technological features in it. The interplay of social interactions, affective aspects and technology was relatively less explored at the primary school level. Learning episodes must be studied at micro and macro levels to study the process and interplay of various factors. Qualitative methods are appropriate for such a study. The case study method is considered well-suited for this kind of study (Maxwell, 2012). I focused on understanding the dynamic relationships between social, affective and cognitive factors and how technology facilitates them. I had to characterise classroom interactions by generating detailed descriptions of classroom activities (Ponterotto, 2006). To get an insider view and an in-depth understanding of classroom processes, I became a participant observer (Bertram & Christiansen, 2014, p. 81).

Participation in both studies helped me understand the classroom activities in detail. It also helped me gain the students' trust, which was helpful during the focused group discussions. It also helped me make sense of students' actions in video recordings as I knew their histories in the classroom. It was possible as participatory research allows greater sensitivity and reflexivity (Bertram & Christiansen, 2014, p. 81). Figure 3 describes the process of research. In the sections below, I give an overview of the research methods used, the data collection process and analysis details for each study. I add more details about these aspects in chapters (Chapter 4, 5 and 6) where I describe respective studies.

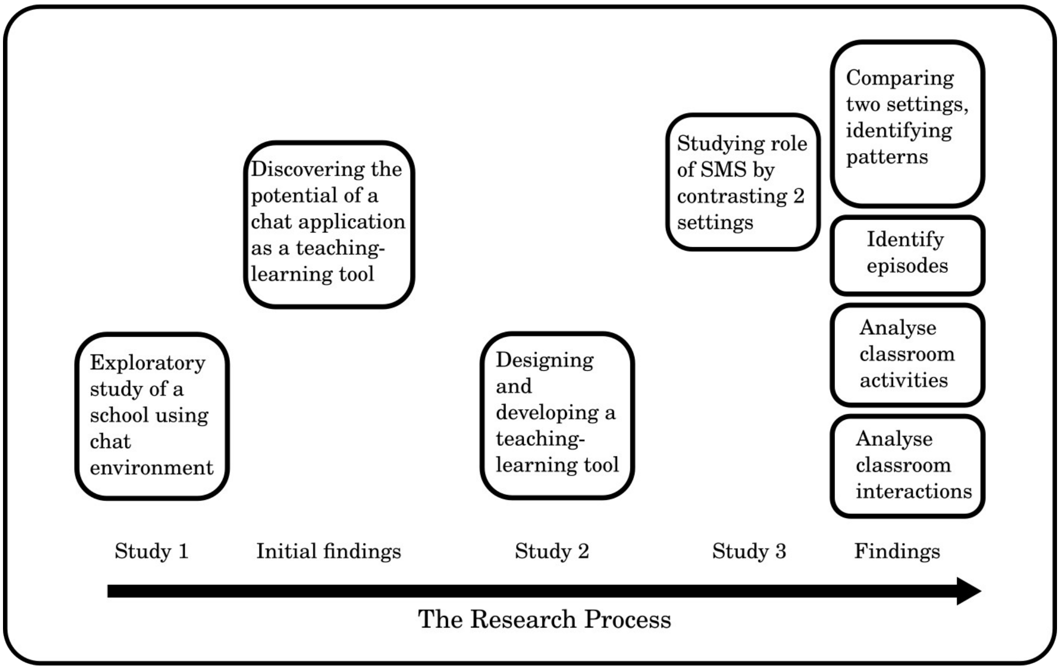

Figure 3: *Illustration describing the research process followed for this thesis.*

3.3 Research method for Study 1

Study 1 was exploratory and was conducted to explore the possibility of using Chat activity as a learning tool. Considering the nature of exploration, I adopted a qualitative approach and an exploratory case study as a research method. A case study, according to Yin (2003), is a qualitative research method where the researcher deeply investigates a specific system or multiple such systems over time. This investigation involves collecting detailed data from various sources. A case study is an in-depth exploration of real-world phenomena, especially effective in answering 'how' and 'why' questions (Bertram & Christiansen, 2014; Yin, 2009).

The central question that this thesis emerged through Study 1; however, there were no clearly defined research questions at the beginning of the study. The study started with the possible aim of exploring the use of Chat activity in learning arithmetic and, if the learning happens, studying the process. As the study was exploratory, research questions also formed during the study. The exploratory nature of the study with a ‘how’ question and the uniqueness of a small tribal village school using laptops in a classroom made the choice of the case study method appropriate.

3.3.1 Description of the intervention site (Study 1)

I conducted this study in a small tribal village near Karjat, Maharashtra. All the students in the school received laptops under the One Laptop Per Child (OLPC) project. I conducted the study as a participant observer. I visited the school once or twice weekly for six months with the Gnowledge-lab team of HBCSE.

The village school has been introduced in Chapter 1; in this Chapter, I will present relevant details to the study without repeating the already written aspects. It is a primary government school (see Figure 4). Students who participated in this study came from not only the village but nearby hamlets as well. When the school started, it had just one teacher; however, two teachers worked there at the time of the study. The new teacher was not trained to use laptops in teaching-learning, so he rarely used laptops. Both were male teachers, one in his forties and one in his thirties. Both did not stay in the village; they came from a nearby town on a bike. The new teacher would often go for official work or training. When just one teacher was present, all four grades sat together. When both teachers were present, the new teacher taught grades 1 and 2, and the old teacher taught grades 3 and 4. When I visited the school, I acted as the third teacher and mostly interacted with grades 3 and 4.

Figure 4: *Illustration of classroom setup in Study 1. Students sat on the floor and kept laptops on their lap or the floor. No specific seating arrangement was followed. (Image credit: Karen Haydock).*

3.3.2 Forms of data collected

A case of a classroom learning arithmetic skills through a digital game was studied. Data included field notes I took as participant-observer, computer logs, computer artefacts and student interviews. Every day, students brought laptops to school and carried them back after school. This setup allowed us to study the students' activities inside and outside the school. Computer logs included details like timestamp, which application was used, how long it was used, and snapshots of the activity performed; for example, if the 'paint' application was used, drawings created by students will be automatically saved. In OLPC laptops, each application could be used in solo or collaborative mode; computer logs recorded if the instance is solo or collaborative. If it was collaborative, then other members' machine names were also recorded. Field notes were recorded when I visited the school once every week. I played the role of a participant observer (Bertram & Christiansen, 2014).

Observations I made were unstructured and were recorded in field notes (Bertram & Christiansen, 2014). During my visit to the school, I interacted with the grades 4 and 3 students for 1 hour. I spoke to the students whenever I noticed any interesting activity. These are unstructured interviews and were also noted in the field notes (Bertram & Christiansen, 2014). Students were interviewed before and after the intervention. Interviews were video recorded. The before and after interviews were structured and conducted in a formal setting (Bertram & Christiansen, 2014). Two researchers were in the room; one operated the video camera, and the other asked the questions. Students were interviewed one by one. Interview questions were aimed at probing students’ arithmetic skills. The questions were designed in consultation with the Mathematics Education group at HBCSE. Study 1 was a smaller part of the bigger "One Laptop per Child" initiative conducted in partnership with OLPC Foundation, USA, Gnowledge Lab of HBCSE and Digital Bridge Foundation, Mumbai. At the beginning of the project, the school, teachers, students, and parents were comprehensively briefed about the objectives of the project. Their participation, in the bigger project and the specific research component was contingent upon informed and voluntary consent.

3.4 Research method for ChatStudio development (Study 2)

For Study 2, I decided to create a digital game called ChatStudio[6] by modifying the Chat application used in the previous study. To provide a comparative case for Study 3, I developed two different versions of the game. In Computer-Supported Collaborative Learning (CSCL), design-based research (DBR) is a commonly used approach for designing and developing educational tools. However, I followed a process similar to product design, where the development of the application involved iterative stages of design, testing, and reflection (Stahl & Hakkarainen, 2021). This process shared some similarities with the DBR

[6]Source code of ChatStudio can be found here: https://github.com/gnowledge/ChatStudioSelf

process. The study took place in the Gnowledge-lab[7] of the Homi Bhabha Centre for Science Education in Mumbai. Initially, the two versions of the ChatStudio application were tested in the Gnowledge-lab and later in a school setting during Study 3.

3.5 Research method for Study 3

As mentioned earlier, in Study 3, I narrowed our focus and decided to study the role of shared memory space (shared screen) in learning. Specifically, Study 3 was conducted to answer research questions 3, 4 and 5, which are listed above. They all are 'how' questions and trying to uncover how SMS influences/affects the students' engagement, disciplinary learning and construction of status. To answer these questions, I had to study the classroom processes in detail. The case study method is one of the research methods that can be adopted while probing the learning process (Yin, 2003). Considering this, I decided to adopt a case study method. However, I also needed to separate the effect of SMS from other variables, such as a change in pedagogic approach, the novelty of computers, gamification of the task, etc. I decided to choose the 'comparative two-case study' method. Where two cases are studied in detail, these two are similar to each other in most aspects and only differ in one or two aspects.

To explain the two-case study design, Yin (2003) shares an example of a study by Elmore et al. (1977) in which they selected two case studies to illustrate contrasting strategies for designing and implementing educational accountability. One case was a basic version of an accountability system, whereas the other was a higher-cost, more complex version. Many researchers have used such two-case study designs (McCoy & Lynam, 2021; Nguyen, 2022; Pargman, 2003).

Yin (2009) notes that two-case study designs can help address some of the criticisms of the single-case study design:

"In general, criticisms about single-case studies usually reflect fears about the uniqueness or artifactual condition surrounding the case (e.g., special access to a key informant)." (Yin, 2009, p.54).

[7]https://www.gnowledge.org/

In my case, I chose a case with an SMS and another without it. The contrast of the two cases helps in linking/discounting observations with the presence or absence of SMS.

3.5.1 Description of the intervention site (Study 3)

The village school was ideal for study 3 as it had necessary resources such as laptops, servers, charging stations etc. However, the number of enrolments had fallen due to employment-related mobility. Families had to move to nearby places for work, and children moved with them. The school had only a total of 12 students. Because of these reasons, I decided to look for another school for this study. Finding a research school was difficult for multiple reasons. Many schools do not allow outsiders to enter schools due to various reasons. I spent considerable time and effort getting permission to conduct the study in a government-run school linked to a child rehabilitation centre. After running from office to office and not getting permission, I decided to give up that school and look for another school. After approaching many schools, I found one school in the M ward area of Mumbai that allowed me to conduct the study on their premises and with their students.

This was a semi-government school affiliated with the Maharashtra state board, and the medium of instruction was Marathi (a regional language spoken in Maharashtra). The school’s Head Teacher was enthusiastic and cooperative. I told her I wanted to study with students in grade 4. She agreed, but with the condition that I do it with a class of students who are average performers. The school had multiple divisions for each grade, and they were organised based on the student's performance in annual exams. Those who performed above average were put in one division. At the same time, all average students were put in another division. The division I was assigned had 45 students who performed lowest among all. The school chose this arrangement so that the students who perform poorly can be taught differently than other students.

The school had a very tight schedule as practically two schools ran on one campus. Classes for grades 5 to 10 happened in the morning shift (7:30 am to 12:30 pm), and classes for grades 1 to 4 happened in the afternoon shift (12:30 pm to 5:30 pm). I was given the last 45 mins in the afternoon shift 4:45 pm to 5:30 pm). I visited the school every day between 4:30 pm and 5:45 pm. The class teacher was friendly, and she helped me conduct the study. Through discussion, we divided the 45 students into two groups, keeping the gender ratio the same. One group would stay in their regular classroom, and the class-teacher would teach them as before. Another group would move to another room (any room available), and I used to engage with them for 45 mins. So effectively, every group came to my class on alternate days.

This setup also helped me, as we had just 30 working laptops. Sourcing laptops was not challenging. Gnowledge-lab had old OLPC laptops. We managed to put 30 working laptops together by cleaning, upgrading, and swapping parts of many laptops together. Classrooms in the school did not have charging points. Therefore, I used to charge all the laptops using a mass charger every night and take them to school in a bag daily. Even though laptops were old, batteries would last 45 to 60 minutes once fully charged. I would also carry a few fully charged extra batteries for emergencies.

Finding a school, getting permission and conducting a study helped me understand the school system. It was challenging to conduct a research study in a school instead of a controlled lab environment. The duration of intervention had to be extended as, on multiple days, my class had to be cancelled as students were busy with some school-related task or no space was available to conduct the class. Even though I was given a classroom-session of 45 minutes daily, the first and last few minutes would go into distributing and collecting laptops. So the effective duration of the class was only 30 minutes. For data collection, each student needed to get the same laptop every time. Therefore, as a teacher, I would read students' names individually and hand over the laptop to ensure each student gets the same laptop every time. Students often showed interest in staying longer in the class, but that could not be done as it was the last school period.

3.5.2 Forms of data collected (Study 3)

As mentioned earlier, I adopted the two-case study method. I audio-recorded each classroom-session and took field notes to capture processes in both settings and generate 'thick' descriptions. I did not get permission from the school administration to video-record all the classroom-sessions. However, they allowed me to video-record one session from each setting. Computer logs from each laptop were collected regularly and saved on a different computer. A separate pen and paper test was conducted to check students' arithmetic knowledge before and at the end of the intervention. The test was designed and validated by the Mathematics Education team at Homi Bhabha Centre for Science Education, Mumbai. Focused group discussions[8] (FGD) (Hennessy & Heary, 2005) were conducted with all the students at the end of the intervention. These sessions were audio recorded. To get students' views about various aspects of intervention, I chose focused group discussions over personal interviews, considering students' ages. Young students find FGD setup less threatening than personal interviews (Donaldson, 1978; Fraser, 2004). The class teacher was also interviewed. In this research study, formal consent was secured from the Head Teacher and participating teacher through signed documents. Before granting the permission, the Head Teacher spoke to the students and their parents. They were informed about the research's purpose and their voluntary participation. After the Head Teacher received verbal consent, she formally permitted the study.

3.6 Data Analysis

In the case study method, the data from multiple sources and viewpoints are used to create a holistic picture of the phenomenon being studied. Computer data is also used in CSCL, along with data sources such as interviews, focused group discussions, video/audio recordings and field observations. Computer data can include metadata, transcripts, digital artefacts, screen recordings, etc. I used the case study method in Study 1 and Study 3. Whereas for Study 2, I used a process similar to product design. I describe the method of analysis one by one:

3.6.1.1 Data analysis method for Study 1

In Study 1, I was trying to see if 'Chat Activity' can be used as a learning application, and if yes, then how does learning happen, and what feature/s are central to it? To answer research question 1, I used pre- and post-interviews. Checking learners' conceptual understanding

[8]A FGD is a conversation guided by a moderator and involving a limited number of participants, aiming to explore the participants' experiences, viewpoints, and/or opinions (as described by Hennessy & Heary in 2005).

before and after an intervention is the most commonly used method as an indicator of any impact on learners' understanding. The most preferred pre- and post-test method is a pen and pencil test, which has some clear advantages, like it is easy to administer and analyse. However, the paper-pencil test has one issue for young learners. It generates exam-related anxiety, which can affect the quality of data (Fraser, 2004). Therefore, considering the participants' age, I used structured personal interviews to test students' knowledge of arithmetic before and after the intervention. The interviews were viewed to check the change in students understanding due to intervention. To answer research question 2, I used field observations, computer logs and interviews. For the analysis, I used tools drawn from the distributed cognition framework (Hollan et al., 2000; Hutchins, 1995). The distributed cognition framework helps understand sociotechnical systems. Sociotechnical systems involve human beings and machines, and representations are created, shared, and manipulated through both humans and machines, inside and outside the 'head'. A computer-supported classroom is a sociotechnical system consisting of a teacher, students and computers. More details about the analysis process are described in Chapter 4.

3.6.1.2 Data analysis method for Study 2

Study 2 focused on the design and development of an application called ChatStudio (explained in detail in Chapter 5). Therefore, in this study, the aim was to check if the application was working as intended. During each cycle, we analysed field notes, interviews and computer logs. For analysis, we adopted a method similar to the one used in product design and development. It is an iterative process in which each iteration of the design and testing process involves a multifaceted examination of the application's performance and user experience.

In each cycle, we looked at field notes and interviews to check if each feature of the ChatStudio application was working as envisioned. Then, we looked at computer logs to check if data and meta-data were getting recorded as intended and if it was accurate. Next, we paid close attention to the experiences and challenges faced by participants while using the ChatStudio. For this, we used data from field notes and informal interviews with the participants. We focused on identifying participant perceptions of the ChatStudio application and its various features. We also monitored the performance of the application using the computer logs generated during the user interactions. The aim was to identify any technical glitches or performance issues that needed attention and fixing. The same iterative process was followed for each cycle of designing and testing. Feedback from one cycle informed the next, leading to continuous improvement.

3.6.1.3 Data analysis method for Study 3

Similar to Study 1, Study 3 also had data from multiple sources. I was trying to answer three research questions through this study. Considering the nature of the questions, I adopted two different methods for analysis. The first method was quantitative, which was used to get an answer to research question 3, which was about engagement. In CSCL, quantitative methods are often used to analyse computer logs. Metadata captures data about how the learner used various applications. Extracting the date, time and duration of usage can tell us about learners' engagement with various applications. Such data is used to get a coarse-grained idea of a learner's behaviour, as such data does not tell us anything about cognitive engagement. Such data needs to be triangulated with data from other sources. The strength of the case study method is that it tries to capture phenomena at multiple levels through multiple data sources. I used the computer logs to get the bigger picture of the intervention. Next, I analysed the video-audio data. I used it to get the moment-to-moment picture inside the everyday classroom. For this, I used a method inspired by Flewitt’s (2006) method. I first created dynamic text from the video-audio data, then coded the text thematically and finally counted the occurrence of each code. Here, the dynamic text is a textual description of the video data that includes verbal, temporal, spatial and kinaesthetic information (Flewitt, 2006). I counted codes to get an idea about the pattern of interactions inside both the classrooms (CSS and CSG settings) and also looked at the context of the interactions.

I used tools drawn from conversation and interaction analysis to answer the remaining research questions. Stahl et al. (2006b) have used conversation and interaction analysis to uncover learning processes in face-to-face and virtual classrooms. In CSCL, conversation and interaction analysis is often used as it allows you to uncover complex interactions (Stahl, 2006)

3.6.2 Addressing issues of validity

In the studies presented in this thesis, I used qualitative research methods. In qualitative research broadly, there can be two threats to the validity: researcher bias and reactivity (the effect of a researcher on the individuals or setting they are studying). We have to address these issues of validity "by using evidence collected during the research itself to make these 'alternative hypotheses' implausible" (original mention) (Maxwell, 2012, p. 240). Eliminating the impact of the researcher's action is impossible; instead, the goal is to use the influence productively. When a researcher plays the role of a participant observer, reactivity is not a serious threat to validity as the participant observer has less influence than the setting itself (Becker, 1970). Whereas for "bias", it is crucial to understand the exact nature of impact the researcher has on participants/interviewees and think about using it (ethically) to answer your research question (Maxwell, 2012). I used the case study method, and to address the validity issues, Maxwell (2012) suggested a few checks; I used some of those checks they are listed below:

- **Intensive, long-term involvement:** I interacted with the students and teachers for a long time, and my involvement was extensive. In study 1, I visited the school for a year and collected data for six months. In study 3, I visited the school for more than six months. Long-term participant observation leads to a collection of more complete and good-quality data.
- **"Rich" data:** I collected multi-modal data from five tools (audio/video recording, observation notes, focused group discussion, computer logs and pen-paper test). Long-term involvement and use of multiple tools enabled me to collect 'rich' data. In qualitative studies, data needs to be 'rich' and varied to create a full and detailed picture of what is happening (Becker, 1970).
- **Triangulation:** I used data from multiple sources to triangulate results. Triangulation "reduces the risk of chance associations and of systematic biases due to a specific method and allows a better assessment of the generality of the explanations that one develops" (Maxwell, 2012, p. 245).
- **Comparison:** In study 3, I studied two cases. Even though I focused on classroom learning by using a game with SMS, I had another case of classroom learning through

a game without SMS. The second case was for comparison. Comparing two cases in a two-case study method helps see and interpret the focused case (Maxwell, 2012).

- **Quasi-Statistics:** Wherever possible, I have used simple numerical results. For example, in study 3, I counted the interaction events and presented them in numbers to get an idea of the type and context of interactions. Becker (1970) called such simple numerical results 'quasi-statistics', which means numerical results derived from the data. He claimed that most case studies fail to show the quasi-statistical basis of their conclusions (Maxwell, 2012).

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

This chapter centres around a study that originated as a design challenge presented by a school teacher, which ultimately guided the selection of the research problem for this thesis. I begin by elucidating the design challenge and providing a detailed contextual understanding encompassing the village, school, laptops, teachers, and students involved. Comprehending the context is vital for comprehending my design choices. I thoroughly examine the entire process and describe the methodology adopted, including the data collection methods employed. Subsequently, I present the observations, results, and their detailed analysis, focusing on the efficacy of the digital game in facilitating children's learning. I scrutinize the reasons behind its success if indeed it proved effective.

4.1 Study Site and Design Problem

In the year I joined the PhD program, the Gnowledge lab1 at Homi Bhabha Centre for Science Education initiated a field project in a small tribal village near Karjat, India. This village had a small primary school that captured my interest due to its use of specially designed laptops (called XOs) by all students. Professor Nagarjuna of HBCSE and other team members regularly visited the village. During one such visit, I had the opportunity to accompany the Gnowledge lab team to the village school. To reach the village, one had to traverse the Mumbai-Pune expressway, transition to the old highway, navigate a small tar road, and finally take a mud road. After a journey spanning approximately 65 km, we arrived at the research site. The village consisted of modest mud-brick houses with bamboo roofs covered in dried hay bundles (see Figure 5). The village lacked a tar or cement road connecting it to a highway. The village was predominantly inhabited by the tribal Dhangar (shepherd) community. It encompassed no more than a hundred dwellings.

The school had one room, and students from grades 1 to 4 sat there. One teacher taught all the subjects to all four grades. Each student possessed laptops specially designed by the One Laptop Per Child (OLPC) Foundation at MIT. These laptops featured Marathi language support, with Devanagari alphabets printed on the keyboards. The teacher assigned various activities to groups of students involving the use of laptops and other learning materials. These laptops seamlessly connected to one another via a local mesh network, facilitating student-teacher and student-student interactions. Despite having only one teacher for all four grades, the classroom functioned in groups, fostering social interactions among students. The classroom featured numerous instances of social interactions, both among students and between students and the teacher.

Figure 5: *Picture of the village, site of the Study 1. In the picture, students can be seen carrying the OLPC laptops. The village does not have concrete or tar road, and houses are simple with mud-brick roofs.*

The teacher had designed sets of activities that were sent to students' laptops, allowing them to complete the tasks at hand. Peer interactions played an important role in the classroom's learning environment. Siblings shared a classroom, regardless of their grade levels, and older siblings assisted their younger counterparts with their tasks. Additionally, friends readily aided one another in various tasks.

The XO laptops were equipped with various applications, each designed to teach concepts or develop skills. However, the teacher identified a need for additional support in numeracy and arithmetic, as the existing XO applications did not adequately address these areas. Consequently, the teacher approached us with this observation, inquiring if we could suggest or design new applications. As a second-year PhD student, I was seeking a topic for fieldwork, and this opportunity aligned with my research interests. The Gnowledge lab team and I took on this project and decided to design an activity to help students learn arithmetic skills. In the subsequent sections, I will elaborate on the infrastructure, participants and our proposed solution.

4.2 The Infrastructure and Participants[9]

The school received XO laptops in 2007 when the OLPC Foundation generously donated laptops to the Digital Bridge Foundation. After careful consideration, the small village school was chosen as the initial deployment site. These laptops, known as XOs, were designed and manufactured by the Media Lab of MIT, Boston, USA. The design was inspired by Seymour Papert's Children's Machine (Kane, 2016). The XOs were specifically created to endure rough use and overcome challenges like limited access to electricity and the absence of network connectivity. In addition, the XOs came pre-installed with a specially designed operating system called the Sugar Learning Platform (SLP),[10] which featured an activity-centred, GNU-Linux-based desktop (see Figure 6). The SLP was also influenced by Papert's constructionist approach to education, which emphasises learning through hands-on experiences rather than traditional instruction (Papert, 1993). The XO laptops and the SLP

[9]This section is published in: 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

[10]https://www.sugarlabs.org/

were developed by non-profit foundations dedicated to research and development in inclusive education using information and communication technologies (ICT).

Figure 6*: Screenshot of home view of Sugar Learning Platform.*

A total of 15 students (eight girls and seven boys) participated in the study. Among them, three students were in grade three, while the remaining 12 were in grade four. These students had been using XO laptops since they were in grade one. Most of the time, the students in grades 3 and 4 shared a classroom. The school had 26 students (see Figure 7), many of whom were siblings. They all belonged to the 'Dhangar' (shepherd) community and spoke Marathi at home. Parents frequently visited the school, and with their support, the students took care of various tasks such as opening and closing the school and cleaning it. Due to its location in a small village, the school had an informal structure. Students would occasionally leave the class to go home and return later. Parents would also come to the school and request assistance with household chores, which the students would willingly perform before returning to school. All the students in grades 3 and 4 possessed reading and writing skills in Marathi.

In addition to Marathi, the students were also learning English and Hindi. Although they could comprehend Hindi, they struggled with speaking it fluently. They were familiar with the English alphabet and could read simple words. The school followed the curriculum prescribed by the Maharashtra State Board.

Figure 7: *Picture of the classroom in Study 1. The school began with a prayer. In the picture, students can be seen reciting a prayer with closed eyes.*

4.3 Initial observations and selection of Chat Activity[11]

Students used laptops both inside and outside of school. During our regular visits, I noticed that students frequently utilised an instant messaging application called Chat Activity (see Figure 8). This application was pre-installed on the laptops and did not require internet

[11] This section is published in: 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

access. The XO laptops were equipped with hardware that supported the creation of a local mesh network, enabling students to receive messages within this network. Since it is a small village, students could connect to the local mesh network from their homes. The Chat Activity proved to be popular among the students as it provided a means for communication and sharing media such as photos, videos, and emojis. (For a more detailed description of the Chat Activity and its features, please refer to Chapter 5).

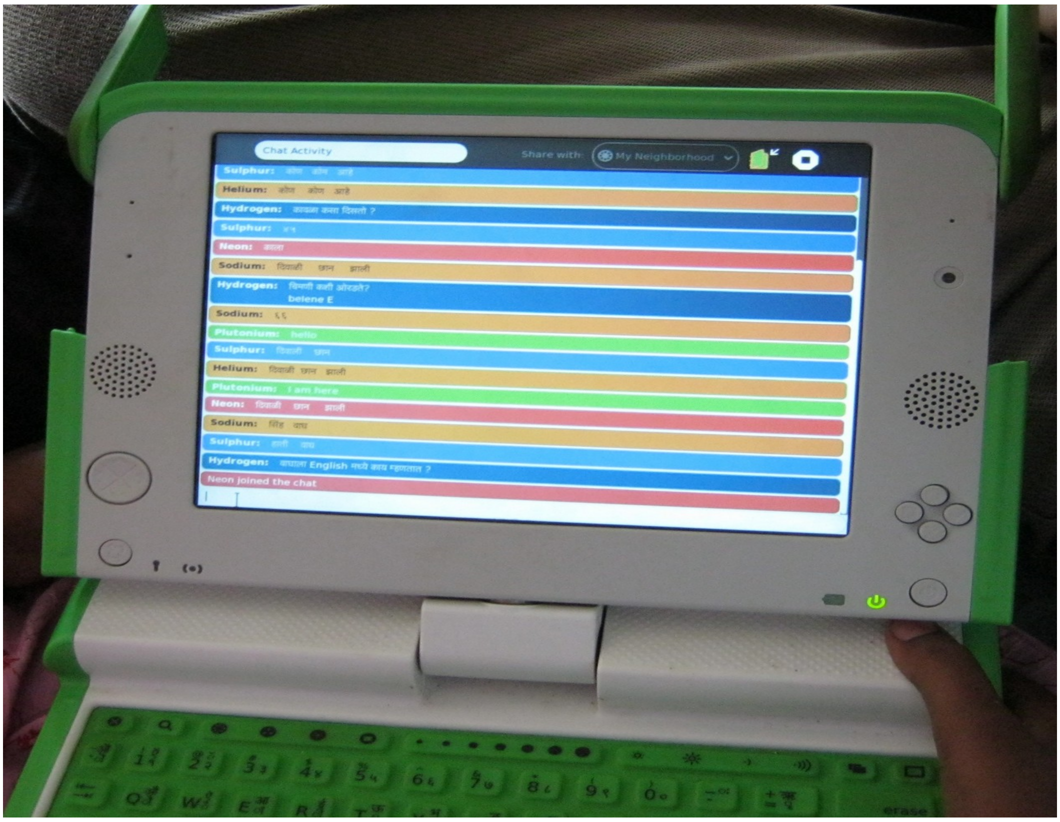

Figure 8: *Picture of XO showing Chat Activity*

Another valuable observation pertained to the games the children played during their leisure time. They would engage in games with simple rules, often in small groups. Many of these games involved the children creating their own rules or improvising existing ones. I saw an opportunity to utilise these observations in designing a learning intervention—a game with simple rules that could be played using the Chat Activity. Additionally, I decided to conduct a study on this intervention with the following research objectives in mind:

4.3.1 Research objectives and questions

- Design a simple number game to facilitate children's arithmetic learning.
- Investigate the learning process through the game mentioned above.

Assess the extent to which students acquired arithmetic skills and determine the role played by different features of the Chat Activity.

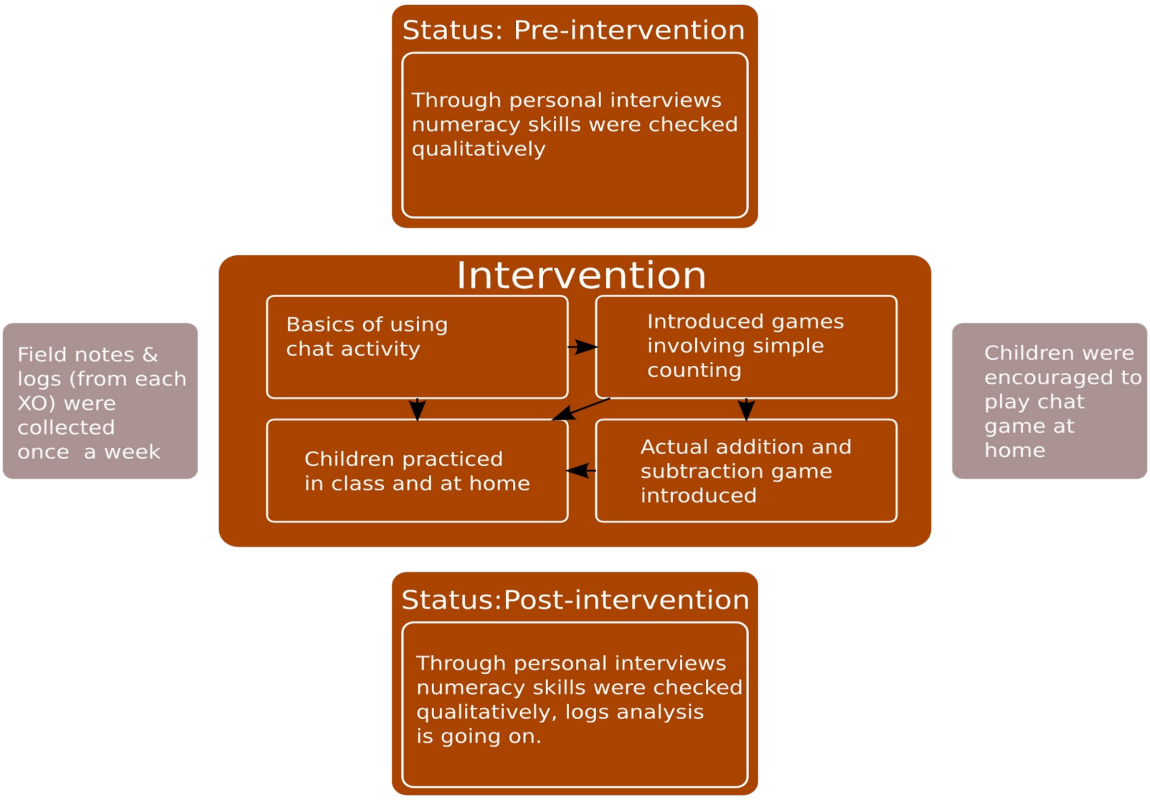

Figure 9: *Research Design of Study 1- Students' numeracy skills were checked before and after the intervention. The intervention involved playing number games on Chat activity. During the intervention, field notes and computer logs were collected.*

As discussed in Chapter 3, I employed a case study methodology for this research. Based on the formulated objectives, I developed two research questions, which were previously mentioned in Chapter 3:

1. Can an instant messaging environment (Chat Activity) be used to teach arithmetic skills?
2. If yes, how does learning happen, and what features help in learning?

Research questions 1 and 2, in the context of Study 1, meant- Can gamified instant messaging on "Chat Activity" improve arithmetic skills for Grade 3 and 4 students in a small village primary school classroom? And if yes, how did it help in learning, what was the learning process, and what role did different features of the digital environment play in the learning? Since this study was exploratory and involved simultaneous development and testing of the learning activity, a case study approach was adopted. The study design is illustrated in Figure 9. Through personal interviews with the students, I assessed their numeracy skills before and after the intervention. These interviews included tasks related to number identification (up to three digits), addition (up to three digits), and subtraction (up to three digits). Additionally, observation notes and computer logs from all the laptops were collected weekly. The intervention spanned approximately five months, with weekly visits to the school. During the initial phase, we taught the students the basics of computer usage and the chat activity (although some were already familiar with it). In the subsequent phase, we introduced simple games using the chat activity, such as counting forward or backwards from a given number (e.g., 1, 2, 3, 4, 5,... 100 or 100, 99, 98,..., 1). The aim was to familiarise the students with the chat activity. In the early stages, the students would display their laptop screens to show us their messages, unaware that everyone else could also see their posts. It took some time for them to realise that all screens displayed the same information and that the teacher could also view what they saw on their screens. Once students understood how it works, they learned to use it to their advantage. Following this phase, we introduced addition and subtraction games. Throughout each phase, students were encouraged to practice their learned skills (see Figure 10).

4.3.2 Pre-intervention test results

The personal interviews sought to understand the students' reading, writing and numeracy skills. I found that their numeracy skills were very poor. Except for three students, others were able to count up to 100, but eight of these students were not able to identify or write a random two-digit number posed by the researcher. Three students made similar mistakes. When asked to write 370, they wrote 30070, a standard misconception known as a hundred-tens conception (Fuson et al., 1997). They were able to perform simple addition tasks with single-digit or two-digit numbers without carry-over. Five students were not consistent while doing this task. Only one student was able to add three-digit numbers (without carry-over). Similar results were seen in the case of subtraction. All students were able to do single-digit and two-digit subtraction without a carry-over, but three of them made many mistakes in this task. One student wrote 2–2=2. Only two students were able to solve sums involving the subtraction of three-digit numbers (without carry-over). All the students were slow in all the tasks except one student (Magnesium; more on him in a later section).

4.3.3 The intervention

We wanted to improve their numeracy skills and also support their literacy skills using the chat activity. The first intervention involved playing a simple addition game, where a student (or teacher) first proposed a number (say 2) and then another number (say 3) that needed to be added to the first number cumulatively. All the chats happened in Marathi. As mentioned in Chapter 1, all the OLPC laptops had a bilingual keyboard, and students had learned to type in Marathi (Devanagari script). In this example, the series proceeds in the following way (2, 5, 8, 11, 14, 17....) Each student creates this series by consecutive addition until a three-digit number is reached. The first student who reaches the three-digit number wins the game (by declaring I WON on a screen or aloud) (see Figure 11). The others then checked all her entries to see if she made any mistakes. If she makes a mistake, she has to start again from the correct element before the mistake. If she completes the series correctly, she goes out of the game, and the others keep playing, and the game continues until everyone reaches the three-digit number.

To start the chat application, someone starts a chat session, and others join that session. Every application including Chat activity in SLP has private and shared options; the user can decide to open it for others or keep it private. As students join the chat, every computer screen shows who has joined. The screen shows the name of the joining person's machine, in the colour of that machine (Every XO has a unique colour, and everything done by that machine carries that colour. This allows identifying different machines just by colour.). When enough people join the session, the students or the teacher decide what game they want to play using chat. For instance, as shown in Figure 11, yellow (Y) suggests playing the 'add 4' game. Blue (B), green (G) and red (R) agree. The next task is deciding which number should be used to start the game. Here again, Y takes the lead and 'starts with 4'. Anyone can start with any one-digit number. With this, the race starts. The game's objective is to reach a three-digit number by repeatedly adding 4 to 4. Students do this addition in a very simple way in the beginning. They look at their last post, add 4 to it by doing mental addition (initially, they used hands to count) and post the answer. For the next addition, they look at this post and add 4 to it.

Figure 10: *Picture of a group in Study 1 playing the number game using Chat activity. Students would get engrossed in the game, as seen in the picture. The teacher also sat in the group and had a laptop, and he used it to monitor the game.*

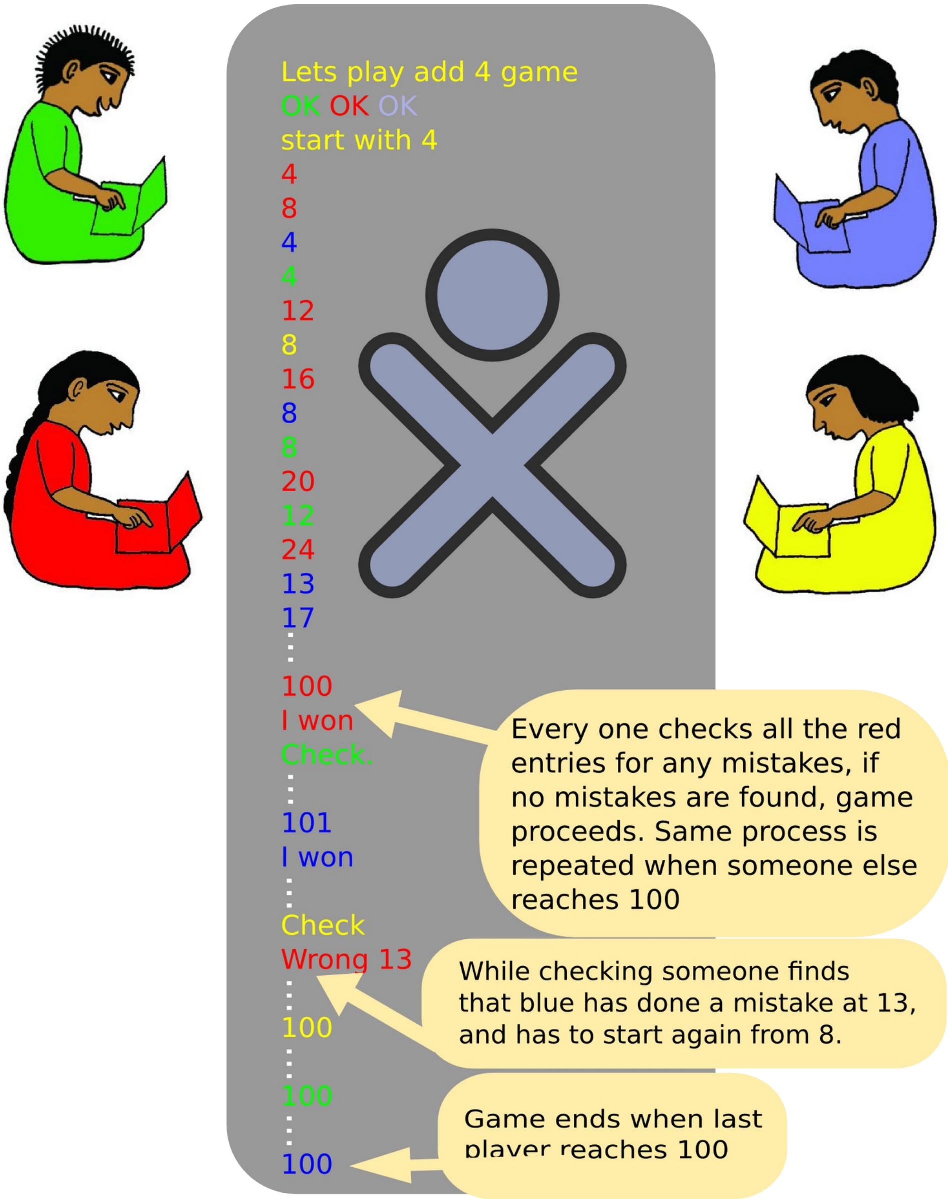

Figure 11: *Illustration describing the number game. Four students, R (red dress), G (green dress), Y (yellow dress) and B (blue dress), are playing the number game. The central brown rectangle shows the view of the Chat activity. Posts are arranged chronologically, and colour indicates the user, e.g. red posts are by student R. Yellow-colored comments describe the steps in the game (Image credit- Karen Haydock).*

In Figure 11, R has posted 4, and then 8. B and G also started by writing 4. By the time B and G reach 8, R has gone up to 16. R leads the race, followed by G, B and Y, respectively. The game proceeds this way. In between, the students look at the screen, scroll using the mouse and see where they are in the race. The game stops for a moment when someone shouts or writes (when students are not in physical proximity) 'WON' or 'I WON'. In Figure 11, R says, 'I WON'. Soon after, someone has to say 'CHECK'. Here, G says it. Everyone checks all the entries made by R by scrolling up using the mouse. They only look for entries in red colour, and see whether she has made all additions correctly. If no mistakes are found, the game proceeds. R (the student who won) still participates in the game, but only when someone else says, 'I WON'. Then R also participates in checking whether that student has made any mistake. The game again stops when B says, 'I WON'. Y asks for checking, and everyone starts checking all the entries in blue. Y finds that B has made a mistake at 13 – instead of 12, she wrote 13 – and all the entries following are wrong. The game resumes, and B has to start from 8 again. This process is repeated till the last person completes the game. In between the games, students find their mistakes, either by thinking about their screen entres or by comparing them with entries made by others. They correct their own mistakes. To keep up with others and increase the speed at which they post their entries, students keep one hand over the ENTER key and the other on the number keys.

4.3.4 Post-intervention test results

After five months of this intervention (3 hours a week), I did a personal interview similar to the pre-intervention interview (n=13). I found that the majority of students had improved their numeracy skills. Eleven students could identify and write numbers up to three digits when the researchers randomly posed the numbers. Before the intervention, most could only identify and write up to two digits. Their speed in identifying and writing numbers had also increased. Eleven students could also solve addition problems up to three digits without carry-over. Similar improvement was seen in subtraction tasks. Ten students were able to solve subtraction problems up to three digits.

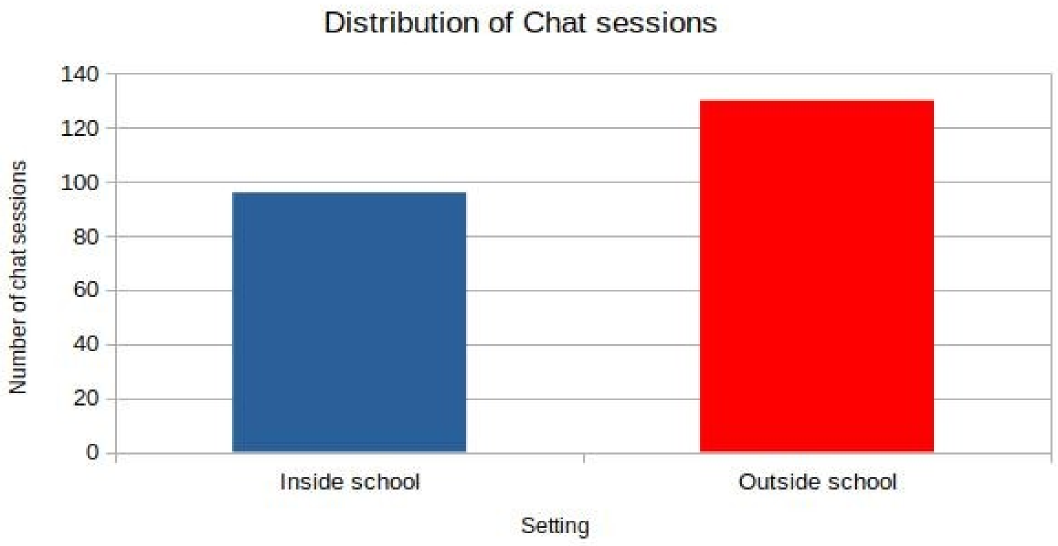

Figure 12*: Graph showing the distribution of chat sessions. On the X-axis is the setting where sessions happened, and on the Y-axis, the number of chat sessions is represented.*

An analysis of the chat logs showed that 226 chat sessions were recorded, with the length of individual sessions varying from a few seconds to 20 minutes. Out of these sessions, 96 sessions were conducted when I was present. The remaining 130 sessions happened during my absence (see Figure 12). The children were initiating more chats on their own, indicating that they liked the number game. Anecdotal evidence also supports this view. For instance, before starting the class, I used to ask the students, "what should we do today?" and mostly the answer was "let us play a number game". It is possible that students responded this way due to my presence; they said something I wanted to hear. Also, the students used to be wholly absorbed in playing the chat activity, and unlike the case of some other programs in the Sugar platform, I never had to force them to engage in the chat activity.

In the early period of intervention, students used to do simple additions using finger-based counting, which is easy but takes time and works only for small numbers. After a while, these students started counting mentally. They also used their knowledge from school (multiplication tables) to solve addition problems (see section 4.4.2). These were significant shifts, possibly catalysed by the competition created by the chat game. To win, students needed to optimise their moves, and school knowledge was helpful in such optimisation.

4.4 The Distributed Cognition of Mathematics[12]

Following Hutchins (1995), I will use a distributed cognition (DC) framework to analyse the role played by the chat activity in our classroom. This framework is suitable for two reasons. One, the chat application creates a socio-technical environment, and DC is among a few frameworks that can be used to understand such environments (Halverson, 2002). Second, learning, in this case, happens through the transfer of representations across many different modalities and a group of learners. Understanding this process requires taking the entire class as a unit of analysis, including the teacher, students and laptops. DC provides a good framework for such an approach (Halverson, 2002). Kirsh's (2010) work also contributed to my understanding of how the structure of the chat activity helped the students and the teacher. In section 4.3, I have provided a detailed procedural description of the tasks performed by the students, particularly what kinds of representations are created, processed and transformed. In the next section, I examine the students' tasks from a distributed cognition standpoint.

4.4.1 A cognitive description of the student's tasks

There are two kinds of cognitive processes going on in the chat activity. The first are the ones we can see directly and are outside the individual student's 'heads' (Hutchins, 1995). Second, the ones we can not see and can only be interpreted involving processes within an individual's 'head'. While playing the game, the students writes a number and post it, creating a persistent external representation that is colour-coded and indexed to an individual poster. This persistent representation helps learning in three ways. One, it allows a learner to notice and focus on her own mistakes and difficulties, as well as track her response time in relation to others' mistakes and response times. Second, it makes it possible for others to

[12]This section is published in: 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

contribute to the student's learning (Kirsh, 2010) by pointing out mistakes and also setting up a peer environment where the student knows that her mistakes are implicitly judged by others in relation to everyone's mistakes. Third, it sets up a turf for constructive competition, as well as a space for improvement in terms of both accuracy and time.

To see the advantage provided by this system clearly, imagine a situation without the chat activity, where the game is played by calling out the number. In this case, the structure is not persistent, and therefore, it is difficult to keep track of, both by the poster as well as by her peers and the teacher. If the game is played by writing on paper with a pencil, it will not be immediately shareable with everyone. If the game is played using a blackboard, it will be immediately shareable, but it won't allow the competitive element to form, as the response speed will be affected.

In the chat activity, the number is written on a persistent external media, which allows the individual student to lower their use of memory space. The same posted number is used for the next addition. The student does not recall the number from her memory; she looks at her previous post and adds to it a number which she recalls from her memory. The number which is taken from the memory (here it is 4, as the game is to 'add 4') is used again and again, and the rehearsal process improves the speed of addition with that number. The complexity of addition also improves, as each instance of addition is with a larger number.

A second important learning event is the comparison between one's own posts and other students' posts to decide where one is in the race and/or to decide whether one did the correct addition or not. For this, a student looks at the entries surrounding her entry. The colour of her entry acts as an anchor and filter, and this reduces the amount of mental effort in processing her rank in relation to others (Chandler & Sweller, 1991).

A third important learning event is the 'CHECK', when someone says 'I WON'. When students check entries posted by that student, the task is a peer evaluation. But this evaluation is easy in the chat situation, as it involves looking for visual similarities (all the entries in that particular colour). This checking is very engaging, as everyone checks the posts on their own screens and sees the posts in relation to both the timing and accuracy of other posts, and the evaluation is quite deep. An individual learner's understanding of a mistake is thus clearer than possible with verbal, paper-pencil or blackboard versions of the game.

In the above description, the learning processes exploit external representations to allow students to focus on specific processes and not get overwhelmed by others. To use Hutchins's (1995) terminology, in the chat game, some processes migrate to a socio-technical system (in this case, the class with computers). In contrast, other processes are performed by students mentally. One such process is mental addition. This process is important in our case, as we want students to learn to do addition mentally quickly (and, say, not on a calculator on screen). The chat activity contributes to reducing the mental effort each individual in the group has to put in while playing the game, and it makes it possible to focus the cognitive resources of the group, making them available for learning the mental addition task individually, as well as while acting as a group in helping others learn addition.

Along with addition, other processes are also performed mentally, such as: 1) deciding what strategy to use for the addition task, 2) trying to adopt a new strategy from information collected from looking at others' posts, or 3) trying to find a new strategy. These are precisely the higher-level learning-to-learn aspects that we want to teach students. These higher-level features cannot be triggered by designs without chat, as they do not have the dynamic social and competition contexts that lead to strategy-level thinking. They focus only on addition.

The chat activity thus keeps cognitive resources available for what we want to teach students and offloads or distributes most of the other peripheral things to the socio-technical system. The activity also creates a social learning situation where the learner automatically moves to a strategy-level of learning. Apart from learning how to add, the activity provides a very rich context, where the children are not only able to focus on their posts but also track others' performances. They are able to perform not only self-assessments but also assess others' performance. Such learning, where students learn to assess others' mathematical ability and rank their performance in relation to others at a detailed level, is not possible with current ways of teaching mathematics.

It is worth noting here that the students learned to read and write better while playing the game. In order to play and win the game, they had to read and write on the screen, that too at a very high speed. While this is a constraint that comes with the media and the externalisation process, this constraint also led to students improving their reading and writing skills. Learning to write, in this case, type, is difficult for students (Dix, 2008). However, the game context was motivating enough for students to learn to write/type faster and more accurately.

4.4.2 The effects of the social environment

The chat activity happened in a social environment. The students interacted with each other and also with the teacher while they were playing the game. I believe this social environment provides the context for students to improve their mathematical skills and then discover better strategies for solving problems so that they can win the game. The same environment also allows them to learn strategies from others. I will illustrate these two points using a significant event that occurred during our study.

The first event is a discovery of a strategy by a student, and the propagation of this strategy through the class. While playing a special version of the addition game, where one number was proposed, and the same number was added to it to get the series, I observed that one student (named Magnesium) left others far behind in the race. The change was so sharp that it was immediately noticed by me as a participant observer. This happened for the next few games as well, But after that, another student named Sulphur caught up with him. Now, these two students left the others far behind. Everyone noticed this change. After a few games, many of them were doing additions at a similar speed. I tried to understand what was happening and asked the students how they were doing the additions so quickly. Magnesium and Sulphur answered that they were using multiplication tables (which the students memorize in class) for the repeated addition, and this was the reason for the sudden decrease in response time. This strategy works only when the number to be added and the starting number is the same. For this reason, in the last few games, they were also purposefully keeping the two numbers the same.

Note that this shift is a radical one, given that many of the students started off by doing addition with their fingers. Now, not only can they do the calculation mentally using multiplication tables, but they have also learned the connection between addition and multiplication in a deep way, such that they tweak the entire game structure in their favour.

This example clearly shows that students are actively looking for better strategies for optimizing their game performance. In the process, they are discovering patterns and inventing strategies based on what they learn in the classroom. These strategies then propagate through the class. This is possible because of the shareable and persistent nature of the external representations created by the chat activity. When students continuously interact with the external representations, new patterns emerge, which leads to the discovery of new strategies. Sharing the strategy using external representations makes its propagation possible (Kirsh, 2010). I have seen similar patterns when students switched from counting with fingers to sequential addition.

I believe that this discovery and propagation of a new strategy occurred also because of the social environment of the chat activity (Van der Meijden, 2005). Children like competition, and the ‘6 seconds fame’ they get when they win the game. This motivates them to learn or find ways with which they can do the activity faster, and reach the goal before others (Putri et al., 2023). Even when someone reaches the goal very late, I have seen them showing similar joy as the winning students. Also, though they wanted to compete, they were seen cooperating as well. The student who finishes first returns to one of the playing students and begins to support him in reaching the goal. The chat activity thus provides the context for the social learning of mathematics (Stahl, 2009).

The second example features a student named Carbon. During our discussions, I discovered that Carbon's school teacher regarded her as a below-average student, struggling to grasp basic concepts. This perception was formed based on the teacher's interactions with her. According to his observations, Carbon appeared inattentive in class, never participating in activities or answering questions. However, Carbon did engage in the chat sessions, although she refrained from joining the smaller groups of active students. These groups would naturally form during the chat sessions, occupying various spots in the classroom. Carbon, on the other hand, chose not to join any of these groups.

However, during one particular session, a significant change occurred. Carbon performed exceptionally well, finishing games ahead of others and achieving top scores in several instances. Following this event, I noticed a shift in her behaviour. She left her designated place and joined the larger group of students actively playing the game. Subsequently, she wholeheartedly participated in various in-game activities such as assessing, celebrating, deciding number pairs, and assisting others.

In my opinion, Carbon's perceived disinterest in studies and learning stemmed from her inherent nature. She was naturally shy and struggled to express herself in public. Furthermore, the class structure played a partial role in exacerbating her difficulties. At this school, a single teacher often taught students from multiple grades, making it challenging to give individual attention to each student. For students like Carbon, who struggled to speak up, this meant missing out on opportunities for support and guidance. Moreover, there was a prevailing belief that only expressive students were considered good students. Unfortunately, students like Carbon lacked alternative means of expression.

However, the Chat activity provided an outlet for Carbon to participate without the need for verbal communication. It eliminated the necessity to seek the teacher's attention; she could simply type and contribute within the Chat activity. Students had the freedom to choose their activities during class, whether it involved playing the number game or exploring other laptop applications. Even if they opted for the Chat activity, they were at liberty to leave at any time. Field notes and logs indicate that students would occasionally enter or exit the Chat activity throughout the games. Additionally, students were free to sit wherever they pleased in the entire school, unbound by the constraints of a traditional classroom. They could join the Chat activity as long as they could connect to the mesh network.

Following that incident, Carbon continued to actively participate in the Chat activity and gained recognition as a skilled player among her peers. Furthermore, the school teacher's perception of her underwent a transformation. Following is an English translation (translated by me) of comments made by the teacher in Marathi

> *Teacher: Sir (referring to researcher) Carbon (pseudo name) has improved a lot.. initially, I used to ask her to talk.. say something.. speak in class.. but she hardly used to respond.. then I started thinking may be she is a slow learner.. may be she can't understand.. she has some issue..but in game (referring to the Chat Activity number game) she changed.. now I understood that she also can talk.. she do sums.. she changed for good due to game.*

In the above comment, the teacher remarked that he witnessed a noticeable change in Carbon's behaviour and noted her increased engagement within the classroom. This example demonstrates that tools such as the Chat activity create a less intimidating space for students like Carbon to express themselves. Passive participation can ultimately lead to active involvement, fuelled by encouragement from friends or notable performance in the game. Active engagement and improved performance, in turn, have the power to reshape the perceptions of such students, ultimately fostering increased participation on their part.

4.5 Conclusions[13]

In this Chapter, I reported our experience using the chat activity as a social constructivist medium to teach numeracy and arithmetic skills. The task was designed as a game to motivate students to learn numeracy skills as well as literacy skills. The students learned to use multiplication tables as an optimisation strategy. Socio-affective changes were seen in students. This experience provides some pointers on ways to design games inspired by close-to-life social context for not only mathematics but other subjects as well. The study shows that the externalisation of representations can not only offload memory but also lead to a closer focus on the essential task at hand. The design of the game also provided quicker feedback to the students by providing them with a self as well as peer-to-peer assessment

[13]This section is published in: 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

model. This initial study opens up several exciting possibilities to use a simple simulated game-like social environment for an effective and motivating means of teaching, learning and assessment.

Chapter 5. Design and Development of ChatStudio

This chapter begins by reflecting on Study 1, discussed in the previous chapter, and provides an explanation of how Study 2 was conceived. Study 2 required changes to be made to the Chat activity and the incorporation of additional elements to transform it into a digital game. Moreover, a comparative case was needed, which resulted in the creation of a version of the digital game without specific features (SMS). I carefully describe all the stages involved in designing, developing, and testing both versions of the game. The chapter concludes by reflecting on the design and development process, highlighting the valuable insights gained during the journey of creating a digital game.

5.1 A few critical observations from Study 1[14]

1. The students and the teacher enjoyed playing the game. The game was so popular among the students that they even played it outside school. In fact, more sessions of the game were played outside the school.
2. A comparison of students' arithmetic skills before and after the intervention at the individual level showed that they improved.
3. Students devised or discovered new strategies to perform arithmetic operations. For example, students discovered that multiplication tables could be used in addition games if the starting and stepping numbers are the same. Newly discovered/devised strategies spread in the class.
4. Students interacted to assess each other's work and help each other.
5. 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.

While reflecting on the observations from Study 1, 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

[14]This section is published in: Shaikh, 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.

played with laptops, paper and pencil, blackboard, 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. I felt that having a bigger group playing the game simultaneously was important. The shared screen in the Chat activity 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 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 central features of the game and played a role in generating the patterns of learning and interactions that I observed.

However, the intervention in the study presented in the previous chapter had other features such as gamification of the task, norms of the game that encouraged interactions, presence of laptops and student-centric pedagogy. All of it may have played a role in generating the patterns of learning and interactions I observed. I felt that it would be worth studying the role of SMS in shaping classroom interactions and learning. I thought I would also need a contrasting case to tease out the effect of SMS and separate it from other features. In this chapter, I describe how I designed and developed an application and its two versions.

5.2 Need for modification of Chat activity

The Chat activity (application) I used in Study 1 was an instant messaging application. By devising a few simple rules, I designed a number game on top of it. However, the application was not explicitly designed for such a game. Therefore, it had a few issues, such as tracking the students' performance by themselves and the teacher was impossible. Observations in Study 1 showed that during the number games, sometimes students posted so fast that many posts appeared on the screen within a few seconds. To calculate students' reaction time, meta-data needed better resolution. The starting and stepping numbers were orally or textually communicated among the students; having them on screen throughout the session would help. Students also communicated while playing the game, so the system needed to differentiate between game numbers and students' text messages. There were no difficulty levels in the previous game; literature from the game design suggests that having difficulty levels helps keep students focused on mastering the skills. Similarly, literature on educational games also suggests that having a scoreboard or leader-board benefits learners' goal setting and motivation (Nebel et al., 2016, 2017; Park & Kim, 2021; Randel et al., 1992), but the number game did not have any scoreboard or leader-board feature.

Considering all these issues, I decided to modify the 'Chat Activity' into an application customised for learning arithmetic skills. As mentioned earlier, I also needed a contrasting case to tease out the effect of SMS. In the contrasting case, I wanted to keep everything the same except the presence of SMS. Therefore, I decided to modify the Chat activity and make two versions of the modified application—one version with SMS and the other without it. In the sections below, I describe the design and development of the two versions of the digital game. Before I explain what modifications I made, the readers need to understand the structure and features of the old Chat activity.

5.3 Chat Activity and its features

As mentioned in Chapter 4, I used XO laptops developed under the One Laptop Per Child (OLPC) project. In the OLPC project, both hardware and software were designed keeping children and learning in mind. Hardware allowed the creation of a local mesh network that can be used to send and receive messages using applications like Chat activity. The operating system in XO laptops is called Sugar Learning Platform[15] (SLP), and every application is called 'Activity'. The SLP operating system running on XO laptops is a 'Free Software'[16]. 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. All the activities in SLP include an application as well as sharing and collaboration capabilities, a built-in interface to the Journal, and other features such as the clipboard.

[15]https://www.sugarlabs.org/

[16]Free software is a software released under a license that allows users to use, study, change and distribute the software or versions of it freely (for more info, visit: gnu.org).

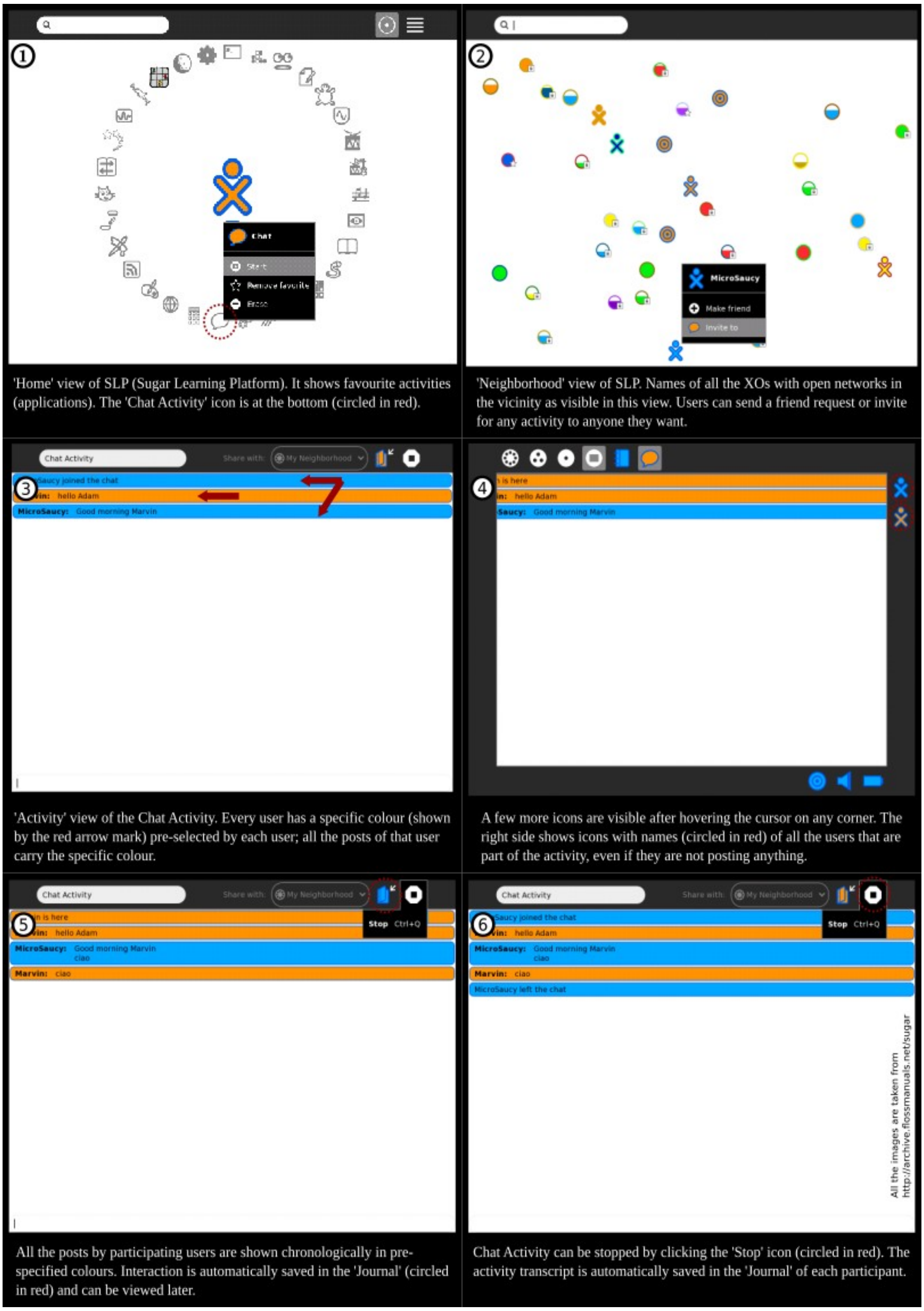

Figure 13: *Series of screenshots showing different features of Chat activity.*

One of the activites is the Chat Activity (see Figure 13), which is a collaborative tool designed to facilitate communication and teamwork among users. It uses the IRC[17] (internet relay chat) protocol. When launching the Chat Activity, its icon will flash in the centre of the screen as the Activity loads. Within SLP, there are two primary modes of collaboration available.

The first mode involves sending invitations to specific friends, granting you control over who joins your Activity (see picture 1 in Figure 13). To invite friends, start the Chat Activity by opening it from the Home View. Then, navigate to the Neighbourhood View or the Group View. Hover over the icon of the friend you wish to invite and click on "Invite to." Afterwards, return to your Activity and begin collaborating.

The second mode involves sharing your Activity in the Neighbourhood View, making it accessible to anyone visible in that view (see picture 2 in Figure 13). Again, start the Chat Activity from the Home View, and then navigate to the Neighbourhood View or the Group View. By sharing your Activity, you allow others to join and collaborate.

Each user's posts in the Chat Activity carry a pre-selected colour scheme, providing a visual distinction. All posts made by a specific user will consistently appear in that user's designated colour scheme (see picture 3 in Figure 13). This colour coding system helps in identifying posts at a glance, enabling efficient communication within the Activity.

Posts in the Chat Activity are arranged in chronological order, ensuring a clear timeline of discussions and interactions. Additionally, all posts are automatically saved in a journal-like format, preserving the conversation history for future reference. Users can access their previous posts and review the entire discussion at any time.

The Chat Activity supports multilingual communication, allowing users to write posts in both English and Marathi. This feature enables participants to express themselves in their

[17]https://en.wikipedia.org/wiki/Internet_Relay_Chat

preferred language, fostering inclusivity and accessibility. Furthermore, users can enhance their messages by incorporating emojis or sharing photos within the Chat Activity, adding a visual element to their conversations.

The Chat Activity offers users a comprehensive platform for collaborative communication. The inclusion of pre-selected colour schemes for user posts aids in easy identification, while the chronological arrangement and journal-like saving of posts ensure an organized and retrievable conversation history. With support for multiple languages, emojis, and photos, the Chat Activity promotes diverse and expressive interactions within the Sugar environment.

5.4 Design and Development of ChatStudio and its two versions

Design and development was a group effort, and it had three people: Rachana Katakam, a programmer; Nagarjuna G, my thesis supervisor; and me. We named the modified Chat Activity with game features the 'ChatStudio'. As mentioned in Chapter 3, we used a process similar to product design. Both versions of the ChatStudio game were developed simultaneously. To avoid confusion, we named the version with SMS as ChatStudioGroup and the version without SMS as ChatStudioSelf. The development of ChatStudio went through an iterative process of designing, testing, and reflecting. Throughout the process, our decisions were guided by a few design features. These designed features were as follows:

5.4.1 Design features that guided the development of the ChatStudio

Our design was based on the experience and observations from Study 1 and literature from the game design community. We used guidelines given by Kirriemuir and McFarlane (2004) for designing educational games. They came up with guidelines based on a review of the literature in this area:

1. A task that the player can complete
2. Focusing on task

3. The task with clear goals
4. Immediate feedback
5. Deep but effortless involvement
6. Exercising a sense of control over one's action

Along with the above guidelines, we used a few other design principles while designing ChatStudio. These design principles are based on a review of the literature we did (presented below). Below, I describe the design principles and also mention how each principle was realised in the ChatStudio application:

1. **Feedback timing affects motivation:**

   Feedback given to learners influences their learning. Immediate feedback is beneficial during classroom activities, while delayed feedback can be beneficial during testing situations. Personal feedback, such as praise, is generally not effective. Timely formative feedback allows students to repeat or revise unsatisfactory tasks (Gikandi et al., 2011; Hattie & Timperley, 2007; Kulik & Kulik, 1988; Shome et al., 2011)

   In ChatStudio: An instant feedback was possible, both from the computer and peers.

2. **Peer collaboration enhances learning:**

   Collaboration with peers in the classroom is a powerful learning method. It helps students construct knowledge through social interaction. Effective collaboration requires active and well-functioning learning teams. Peer learning is important for a child's development and learning (Brown & Palincsar, 1989; Khunyakari et al., 2007; Mehrotra et al., 2009; Roschelle & Teasley, 1994; L. Vygotsky, 1978).

   In ChatStudio: Game-play and norms encouraged social interactions and were supported by technology.

3. **Simple rule-based games and spectators motivate learners:**

Games have the power to make learning enjoyable and motivate children to learn. Educational game design involves creating situations that encourage collaboration and solve compelling problems. Games provide context for learning by doing and can enhance motivation and retention of information (Badheka, 1990; Barab et al., 2005; Bransford et al., 1990; Kiili, 2005; Kirriemuir & McFarlane, 2004; Klein & Freitag, 1991b; Papastergiou, 2009; Squire & Jenkins, 2003).

In ChatStudio: The rules of the game were simple, and it was a social game where the entire class was a spectator.

4. **Externalizing thoughts reduces cognitive load:**
   Writing and sharing thoughts in a group setting, such as an instant messaging environment, reduces the working memory load. Persistent external representation allows learners to track their own mistakes and response times and enables others to contribute to their learning. It also promotes constructive competition and improvement (Hutchins, 1995; Kirsh, 2010; Rahaman et al., 2012).

   In ChatStudio: The application allowed and supported the externalisation of representation. Students externalised representations by typing and posting them on the ChatStudio screen.
5. **Making learning visible to learners, mentors, and researchers:**
   In the current schooling system, learning is often measured through grades or scores, but it is important to make cognitive differences visible. Learners should be able to make explicit connections with their existing knowledge. Visibility of learning helps teachers understand students better and make learning more relevant and meaningful (Kane et al., 2012; Takker & Subramaniam, 2012).

   In ChatStudio: Learning was made visible by generating scorecards, accuracy and reaction time graphs, etc.

5.5 Basic Game[18]

The basic game is similar to the game from Study 1 described earlier. We added a few extra elements to it. We changed the rule that required a student to start again from one step before the step where she made a mistake. In the present game, students did not have to start again. We created three difficulty levels (easy, medium, and high). We also added an option to generate a pair of 1-3 digit random numbers as the starting and stepping numbers. The random number generator was tuned for the chosen difficulty level. In Study 1, the game session ended when every participant had crossed the last number; then, students moved to a new session. For this study, we added a back-end algorithm that generated a scorecard that ranked the students by accuracy and speed (the average time taken by students between steps). Accuracy was the first parameter for ranking. If two students had the same accuracy score, they were ranked based on speed. The one with the lower average time per step ranked higher. The generation of the scorecard became the event that marked the ending of a session.

5.6 ChatStudioSelf and ChatStudioGroup[19]

In both versions, the game interface looked similar and had similar features, with few exceptions. Figure 14 shows the logical flow of the activities in ChatStudio. Figure 15 has screenshots of both versions of the game. To show all the features in a single image, I have taken screenshots of a student's view at the end of the game. The Scorecard window appears when a student clicks the 'Scorecard' button. To show two modes (add and subtract), in the ChatStudioSelf, choose the 'add' mode, and in the ChatStudioGroup, the 'subtract' mode. However, the reader should know that both versions had both modes.

[18]This section is published in: Shaikh, 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.
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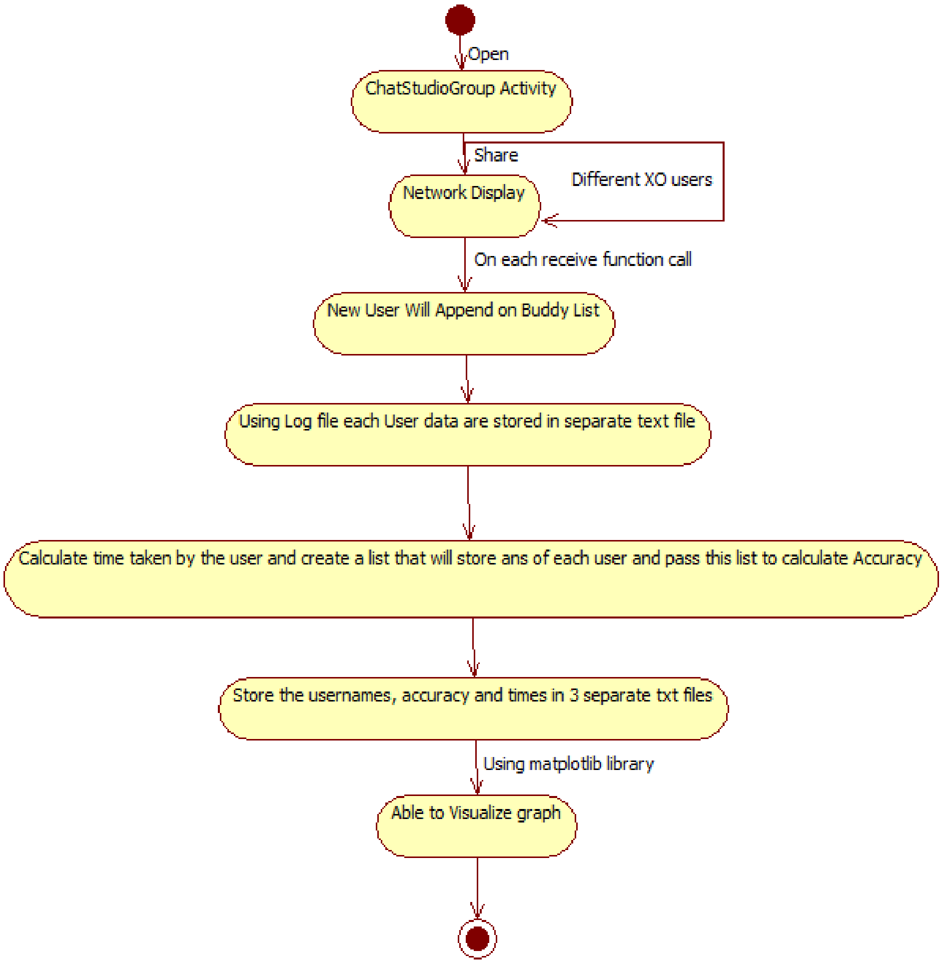

Figure 14: *Flowchart showing the logical flow of activities in the ChatStudio.*

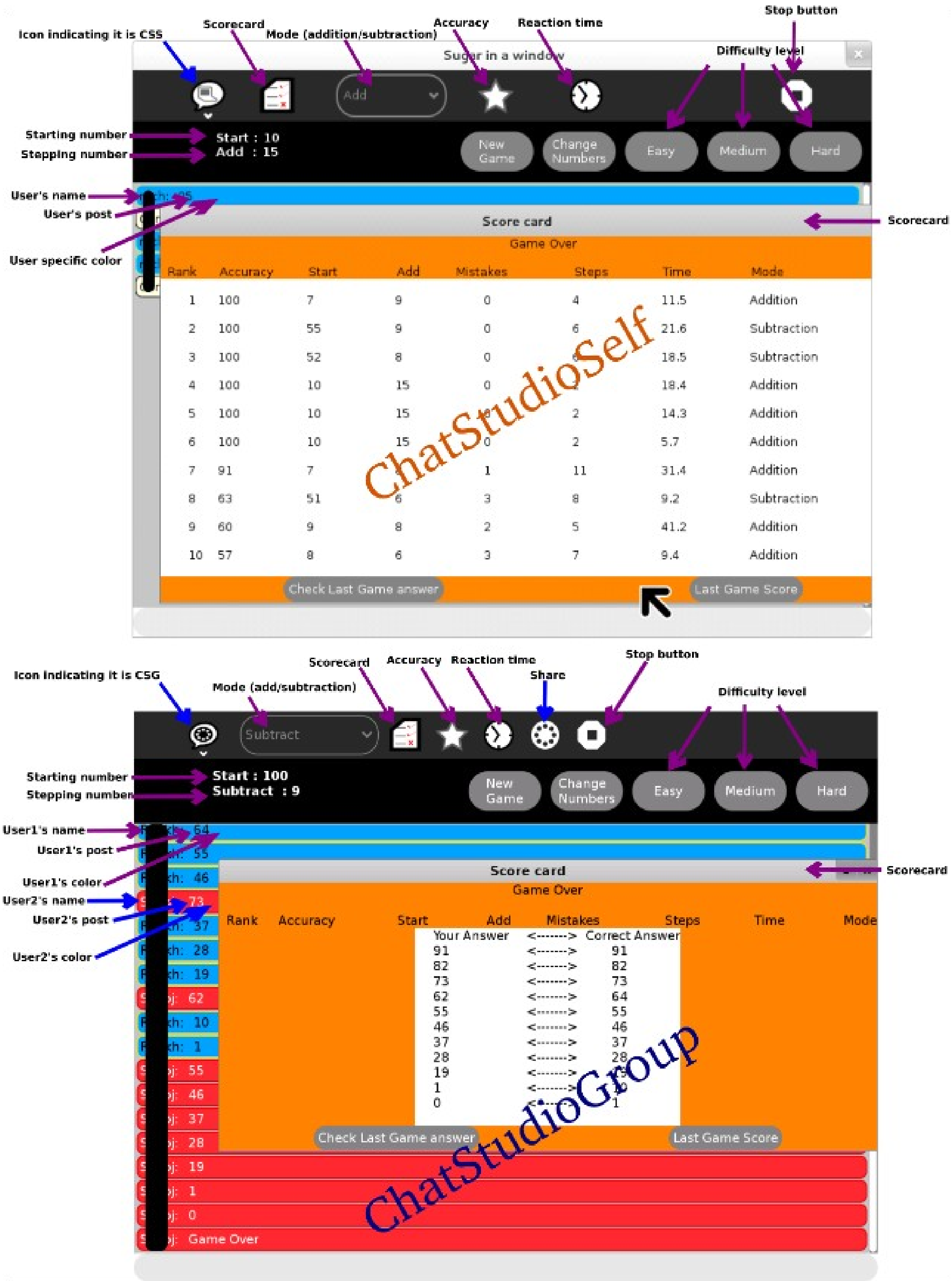

Figure 15: *Screenshots of the two versions of the ChatStudio application. The top screenshot is of the ChatStudioSelf version, and the bottom screenshot is of the ChatStudioGroup version of the game.*

Table 1 lists all the features both versions of the game had. Most features were similar, except that ChatStudioGroup was a multiplayer and ChatStudioSelf was a solo game.

Table 1: *Comparison of the digital environment in two versions of the ChatStudio game*

ChatStudioSelf	**ChatStudioGroup**
Solo	Multiplayer: Students have the option of inviting others to play with them
Students can only see their own posts.	Students can see the posts by all the students in the class, in chronological order of posting, coded by user-specified colour.
Both have “Add” and “Subtract” Modes	
Both have the option of choosing “Easy", "Medium" and "Hard" difficulty levels	
Both allow selecting a custom number pair	
Both have custom colour coding option	
Scorecard ranks students’ own game performances	Scorecard ranks students for that particular game-play by accuracy and speed
Both show accuracy graph	
Both show speed graph	
A badge appears as a “pop-up” if a student correctly finishes a game	There is no badge for accurate game-play.

Along with the digital features, the rules of the games were also very similar. Except for a few rules. Table 2 lists all the steps in both versions of the game.

Table 2: *Comparison of instructional environment and game-play*

ChatStudioSelf	ChatStudioGroup
At any given time, different students could be playing different game configurations	At a given time, the whole class is playing the same game configuration
Since students were playing different configurations, peer assistance was harder.	Since students were playing the same configuration peer assistance was easier.
Students assessed their game on their own, using the scorecard, or by talking to the teacher	In addition to self, scorecard, and teacher, peer-assessment was incentivized.
Students were rewarded with a Digital badge for accurate game-play	Students were rewarded with ranking on the digital scorecard, as well as the scores on the blackboard for peer-assessments.
After finishing, a student can reset the game for a new gameplay	After finishing, students need to wait till everyone finishes, and a new configuration is decided upon by the class.

To give a coherent view of both the games, I describe how each version of the game was played:

1) ChatStudioSelf

In this game version, a student played against the computer. After opening the application, the student selects the mode (Addition or Subtraction) and then chooses the difficulty level (Easy, Medium, and Hard). Finally, the random or custom option is chosen to get the number pair. The number pair has two numbers: the starting number and the stepping number. In the random option, the number pair is randomly generated; in the custom option, a student can insert the numbers of his choice. Once the number pair is selected, a student starts with the starting number and adds/subtracts the stepping number to/from it. For example, if the starting number is '4' and stepping number is 5, and the mode is 'addition,' the game will be as follows:

9→14→19→24→29→34→39→44→49→54→59→64→69→74→79→84→89→94→99→104

The student posts the number for each step on the screen and gets immediate feedback from the computer, as the correct number for that step appears below the student's number but in different colours. The game ends when a student reaches above 50 (easy level) or 100 (medium and hard level). In the end, students get rewards based on their accuracy and speed. The computer's response acts as feedback at each step. The starting number is two- or three-digit (above 50 for easy level and above 100 for medium and hard level).

2) ChatStudioGroup

The gameplay is very similar to the ChatStudioSelf, except here, students discuss and decide the number pair, or the teacher gives the number pair. Once the mode, level, and number pair are chosen, the game starts, and all the students who are playing the game post their responses on the computer screen. All the students can see each other's answers; as the computer's response in the ChatStudioSelf, other students' responses act as feedback. Other rules are similar; students must cross either 50 (easy level) or 100 (medium and hard level) to win. The game continues till all the students cross the winning line. Students get rewards based on accuracy and speed and get additional marks for pointing out other students' mistakes by looking at the postings on the screens. Once all the students finish, the students/teacher decide the number pairs for the second session, and the game continues.

To help a reader visualise how ChatStudio worked, in the following section, I describe the steps involved from starting to ending a game in ChatStudioGroup.

Step 1: Open the ChatStudio application Or go to the mesh network area and look for the ChatStudio application you want to join (see Figure 16 and 17).

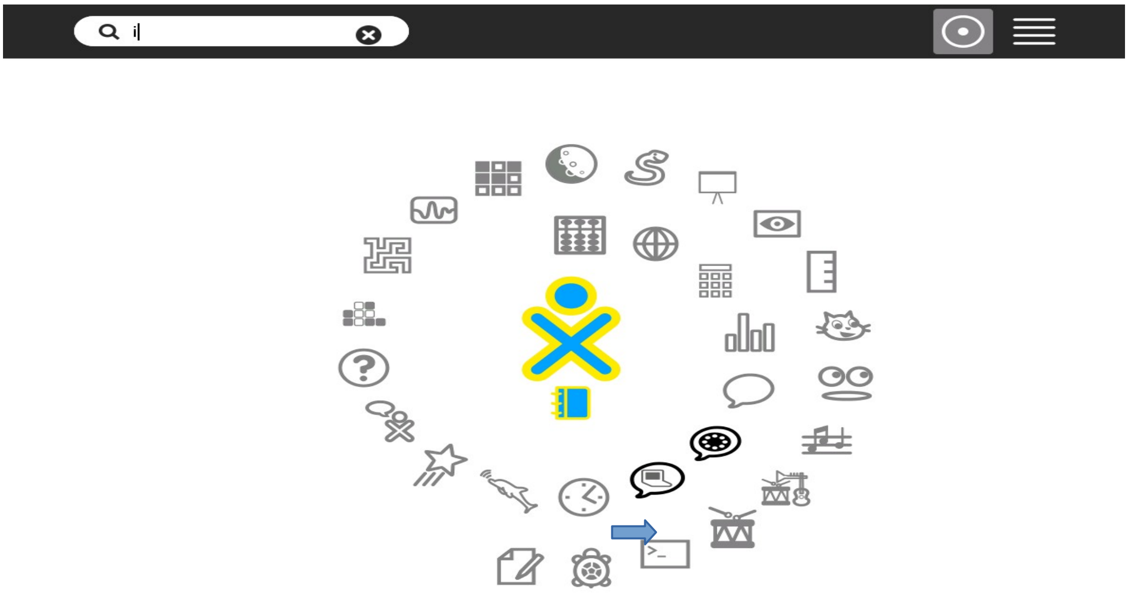

Figure 16: *Screenshot of the 'home' view of the SLP. The location of the icon of the ChatStudio application is indicated with an arrow.*

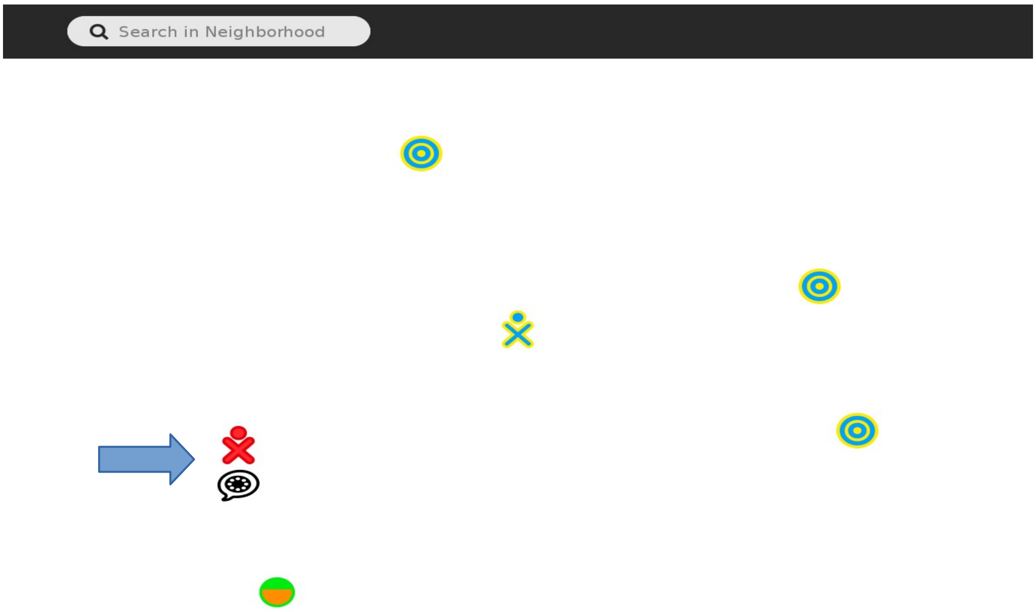

Figure 17: *Screenshot of 'neighbourhood' view of the SLP. The icon of the ChatStudio application would be visible below the 'XO' icon of the user who opened it for the class (see arrow).*

Step 2: A start screen of the ChatStudio application will appear (see Figure 18). Select the mode; it is either 'add' or 'subtract' from the toggle list. And open the activity for others to join by clicking the 'share' button (see Figure 19).

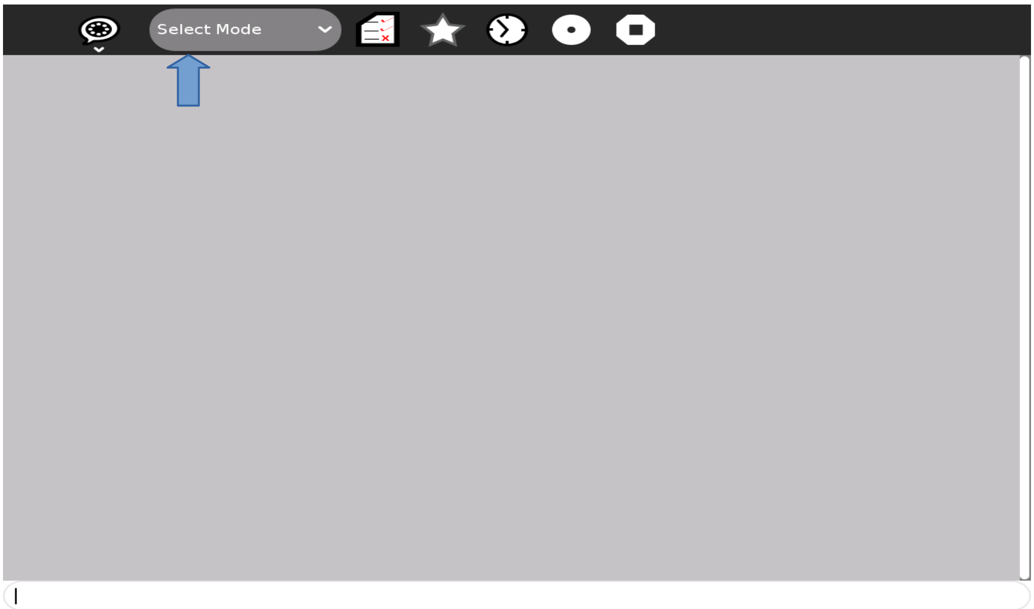

Figure 18: *Screenshot of the start screen of the ChatStudio application. The first step is to select the 'mode' (see arrow).*

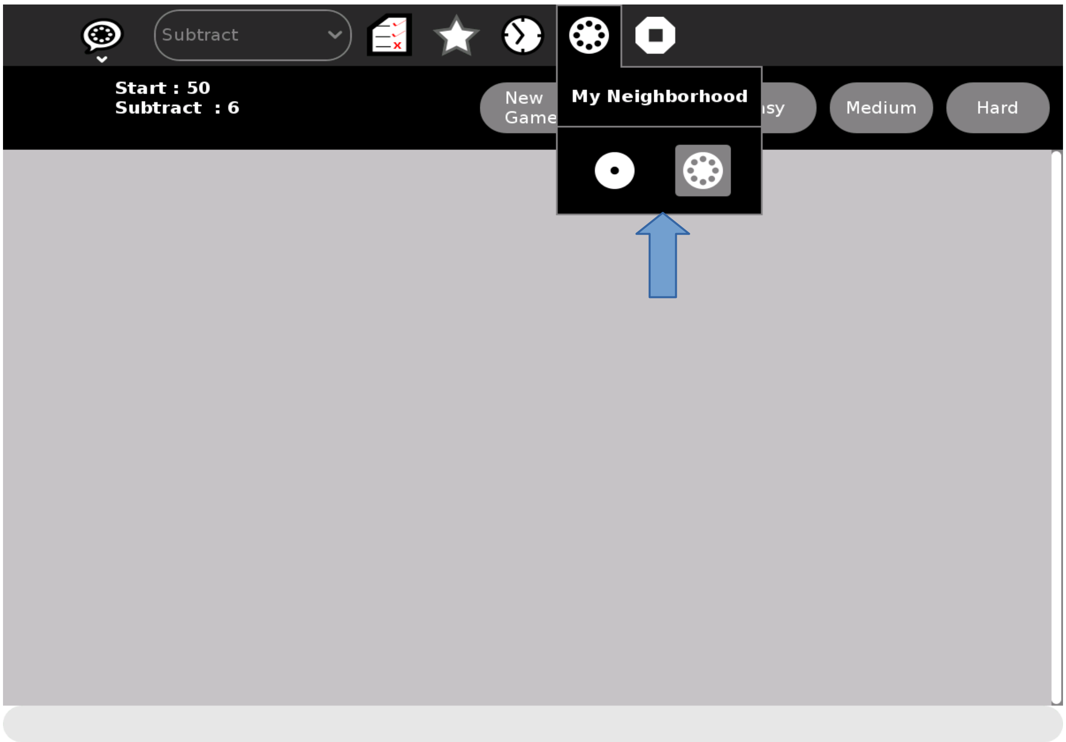

Figure 19: *Screenshot of the ChatStudio application. The user has to click on the 'My Neighbourhood' button to enable the sharing option and invite other users to join the application (see arrow).*

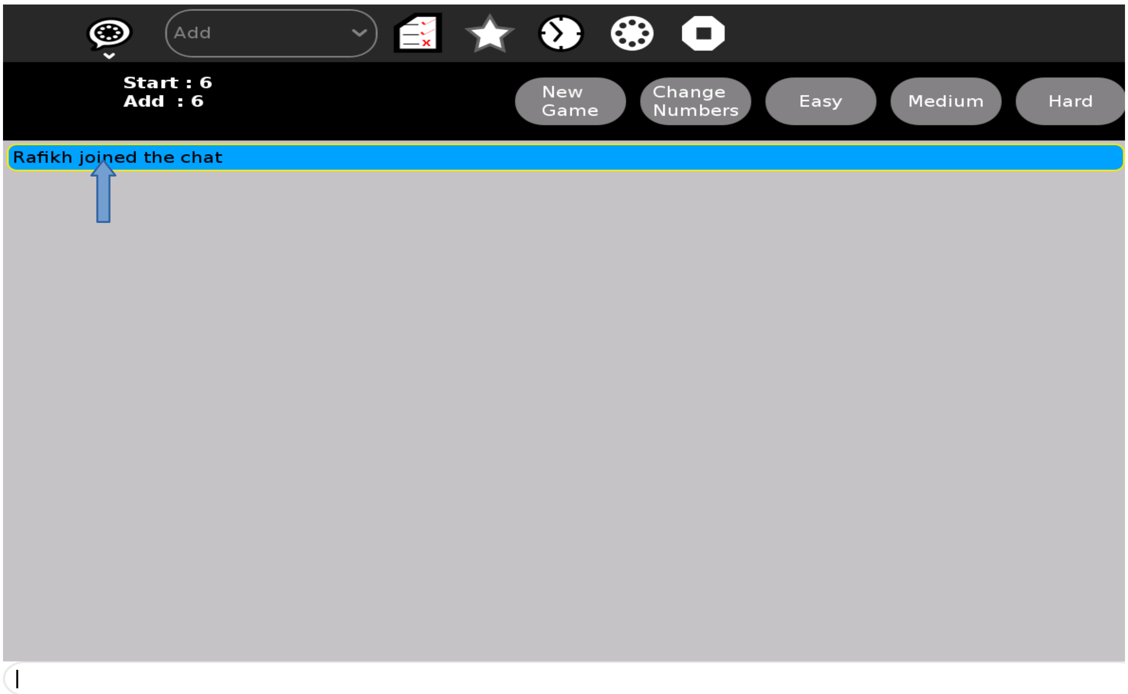

Figure 20: *Screenshot of the ChatStudio application. When a user joins the session, the '--- has joined the chat' message appears on the screen.*

Step 3: A message will appear on the ChatStudio screen that a user has joined it (see Figure 20). Similar message appears when other users join the ChatStudio.

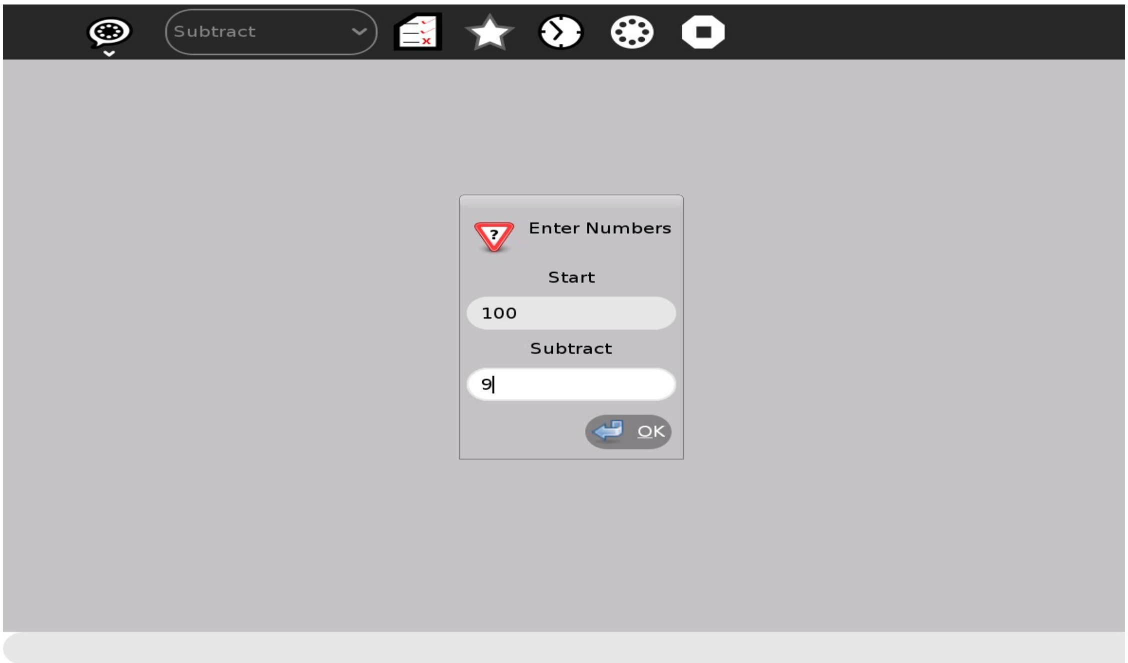

Figure 21: *Screenshot showing input window of the 'custom' option in the ChatStudio*

Step 4: Once all the users have joined the ChatStudio. They discuss and decide the number pair (a starting number and a stepping number) they want to play with. They have two options. Either they can let the machine generate a random number pair (see Figure 20) or put a number pair of their choice (see Figure 21). In the random option, they have to choose any one difficulty level and depending on the level, a number pair appears on the screen.

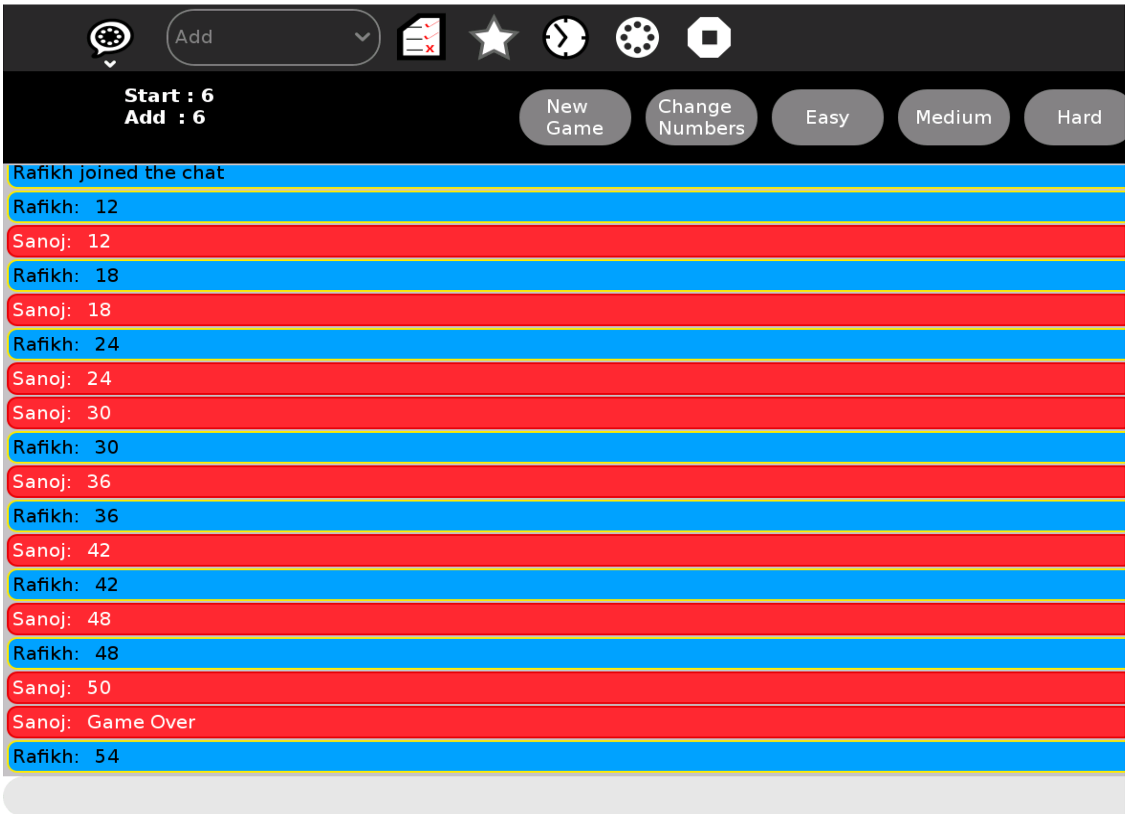

Figure 22: *Screenshot showing an example of a number game in 'addition' mode with starting number as '6' and stepping number also as '6'.*

Figure 23: *Screenshot showing scorecard that appears at the end of each game.*

Figure 24: *Screenshot showing option to compare user's answers with correct answers for each step in the last game session*

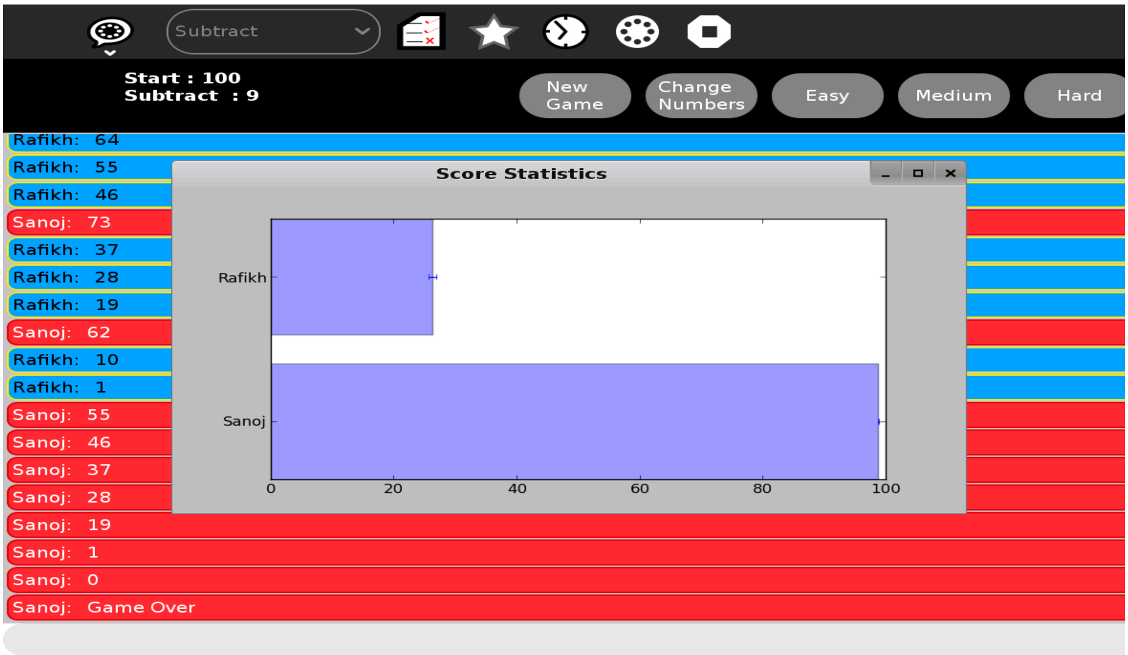

Figure 25: *Screenshot showing bar graph accuracy in last session of the game.*

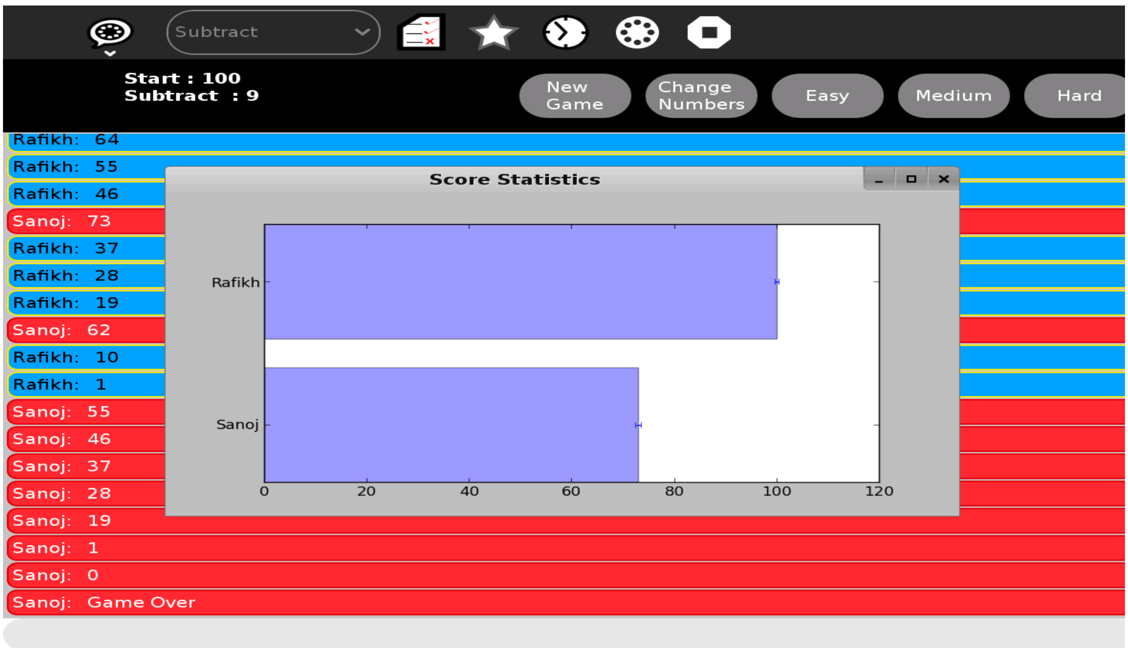

Figure 26: *Screenshot showing bar graph of reaction time in last session of the game.*

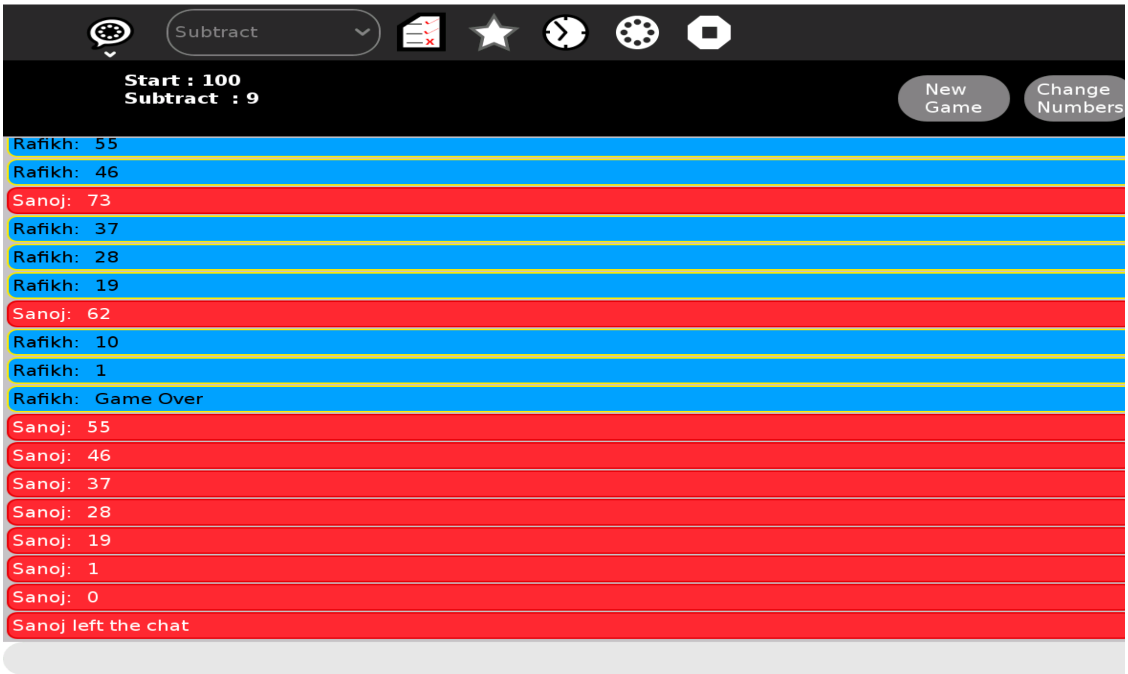

Figure 27: *Screenshot showing a message that appears when any user leaves the ChatStudio application. Check the message in last row.*

Once the 'number pair' is decided, the game starts. During the game, everyone can see posts made by every participant on their screen (see Figure 21). A scorecard appears on the screen at the end of the game (see Figure 23). Students can also see graphs for accuracy and reaction time by clicking the Scorecard button on the screen (see Figures 25 and 26). If any student wants to check the comparison of his numbers and correct numbers for the last game session, she can do it by clicking on the 'Check last game answers' button on the scorecard (see Figures 23 and 24). During the game or at the end, if anyone leaves, a message informs everyone that a specific user has left the game (see Figure 26).

5.6.1 Challenges faced and strategies designed

In Study 1, I observed that the number game in Chat Activity was very popular among students and helped them learn. Students played the game, and they enjoyed it. However, the game had no feature to see their progress over time. We realised the importance of adding new features to the game so that students and their teachers could monitor the progress over time. With this aim, we started designing ChatStudio. Our biggest challenge was ensuring that while adding extra features to the game, we kept the enjoyment aspect. Analysis in Study 1 showed that the fun was due to speed, visibility, and engagement (Shaikh et al., 2013).

Along with enjoyment, we hoped to make the game environment conducive to learning and find valuable indicators to assess the learning. Throughout the development process, we tried to balance these aspects of fun and evaluation of learning in the game.
For example, we added a feature to the game to evaluate each student's performance in a game session. We observed that all the students did not finish their game simultaneously, so if we used the evaluation button early, some students would be left behind; if we waited till everyone finished, other students would get bored. To tackle this problem, we decided to have many evaluation cycles instead of one. Thus, to keep the students engaged, especially those who finished early, we added one more rule to the game: They can check others' answers on their computer screen and earn points if they identify the mistakes made by other students. It solved the problem of faster students getting bored because they had nothing to do, and slower students got more time to finish their game.

The guidelines by Kirriemuir and McFarlane (2004) mentioned above helped us immensely. We used them as a framework to evaluate every change/addition in the game. As school students and the teacher were participants in these studies, and we used to go to school to test the application, we faced many problems. The school had a life of its own. Many programs were going on simultaneously. We would add some features to the game and wanted to test it with the students. However, students would be busy or not in the mood to participate in our activities when they were tired, sad, or excited due to another preceding activity. Due to these issues, the testing got delayed, further delaying the application development, and as a result, we ended up extending the study duration. We could not work out a way around these problems

5.7 Conclusion

In this chapter, I described Study 2, in which we designed and developed a novel application called ChatStudio, building upon critical observations from a previous study. The chapter started by articulating the necessity for modifying the pre-existing Chat Activity application used in Study 1. A comprehensive description of the existing Chat Activity application and its features was provided, serving as the foundation for the subsequent discussions. The core of this chapter delved into the meticulous design and development process of the ChatStudio application. Two distinct versions of ChatStudio, namely ChatStudioSelf and ChatStudioGroup, were developed, one without and one with networks. A detailed list of design features that guided us throughout the development phase offered insights into ChatStudio's functionality and purpose.

Furthermore, the chapter illuminated the gameplay mechanics of ChatStudio, shedding light on how users engage with both versions of the application. A detailed description of the similarities and differences between the two versions of ChatStudio was presented, explaining the unique attributes of each version. The chapter ended by discussing the challenges encountered and strategies devised to overcome them during the design and development process of ChatStudio. In the subsequent chapter, I will describe Study 3, where I employed two versions of the ChatStudio application that was meticulously designed and developed in this chapter.

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

In this chapter, I present Study 3, which investigates the impact of shared screens in a computational game environment on mathematics learning, practices, and the construction of learners' emotions and social status in classroom interactions. Two versions of a simple arithmetic game, as described in Chapter 5, were designed: a solo version for individual play and a multi-player version with shared screens, enabling players to observe one another's arithmetic moves. These versions were implemented in a 4th-grade classroom situated in a suburban school within a large metropolis in India. The study involved video recording classroom-sessions, collecting computer logs, taking field notes, and conducting focus group discussions with the students. Through coding a portion of the data to identify patterns of classroom interactions and utilizing qualitative video analysis tools, I examined specific episodes to comprehend the nuanced dynamics of dominant interaction patterns in each setting. The analysis reveals that the shared screen functions as a shared memory device, preserving all students' contributions, and significantly influences self- and peer-assessments of arithmetic.

In this Chapter, I describe Study 3 conducted to answer the remaining three questions (questions 3 to 5) mentioned in Chapter 3. Chapters 3 and 5 explain how these three questions emerged and how I plan to answer them through a two-case study method.

The research questions for this study were as follows:

> 3) How does a shared memory space (SMS) in a networked computational game environment influence students' engagement?
>
> 4) How does a shared memory space (SMS) in a networked computational game environment affect disciplinary learning and practices?
>
> 5) How does a shared memory space (SMS) in a networked computational game environment influence the construction of social status in the classroom and the public display of emotions by students?

Here, I see the constructs of engagement, learning, practices, construction of social status, and public interactional displays as all coupled in the production of the students' whole experience. In the sections below, I first describe the context and the experiment and then present the results.

6.1 Methods[20]

6.1.1 Context of the partnering school

I conducted Study 3 in a semi-government (teacher's salaries came from the government, rest was managed by the school management) school in suburban Mumbai, India. Marathi was the medium of instruction. Students who participated in the study were from a single classroom taught by a female teacher who taught all the subjects. She is in her thirties and has taught at this school for over five years. Students came from different locations in Mumbai, India's M-Ward (administrative unit of the city municipal corporation) area. Most students were from Mankhurd, Jyotili Nagar, Maharashtra Nagar and Sathe Nagar. Two were from BARC residential colony, and one was from Panjarpol. M-Ward is the lowest-ranking ward on the human development index (Anand et al., 2015). From the teacher, I learned that all the students belonged to families of migrants who came to Mumbai from different parts of Maharashtra for employment. Parents had little or no formal schooling; there was just one student (male) whose mother studied till college (B.A.). Most of the male parents knew how to read and write in Marathi. Most male parents worked as porters or labourers in places such as fish or vegetable markets. Some worked as drivers or cleaners (helpers) on transport trucks. Few did not work at all due to health/addiction issues. Those who work as drivers/cleaners/helpers on trucks sometimes stay away from home for weeks. For most students, female members oversee schooling-related activities such as dropping and picking up children from school, attending parent-teacher meetings, helping with homework etc. Most female members stayed home and did household chores; few worked as domestic workers. The class teacher mentioned that a few had completed schooling till 10th grade and would often inquire about their ward's progress to her. Not all children stayed with their

[20]This section is published in: Shaikh, 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.

parents; some stayed with uncle-aunts or grandparents. Students moved to Mumbai for schooling; their parents stayed back in their native place.

The school had the practice of putting students together based on their exam performance. All the students who perform well and will appear for the 'scholarship exams' are put in one class. In contrast, students with below-average performance are put together in another division. The class teacher mentioned that all the students in her class were considered below average and 'difficult to teach'. She mentions that two students in her class have learning disabilities. She does not know the exact nature of disabilities. Experts from the Municipal Corporation had evaluated them, and one trained person used to visit the school and help them once a month. The teacher said that even though it was a grade 4 class, she had to start from the basics. She had to teach them to read-write and count.

I played the role of a teacher for a 45-minute classroom-session each day during the intervention. I am from the same state as the students and came to Mumbai for doctoral studies. I did my education in schools in small villages and towns where the medium of instruction was Marathi. Students called me 'dada,' which means elder brother in Marathi.

6.1.2 Intervention

As explained in Chapter 3, a total of 45 students from grade four participated in the study. Their age ranged from 9 to 11 years old. Out of 45 students, 29 were boys, and 16 were girls. The school teacher randomly divided them into two groups, keeping the gender ratio the same. Each group was assigned to one of two settings: ChatStudioSelf versus ChatStudioGroup. ChatStudioSelf (CSS) had 22 students and ChatStudioGroup (CSG) had 23 students. Figure 29 shows research design and data collection tools.

Figure 28: *Picture of the classroom setup in Study 3. Students sat on benches made up of wood and metal. Two to three students sat on one bench.*

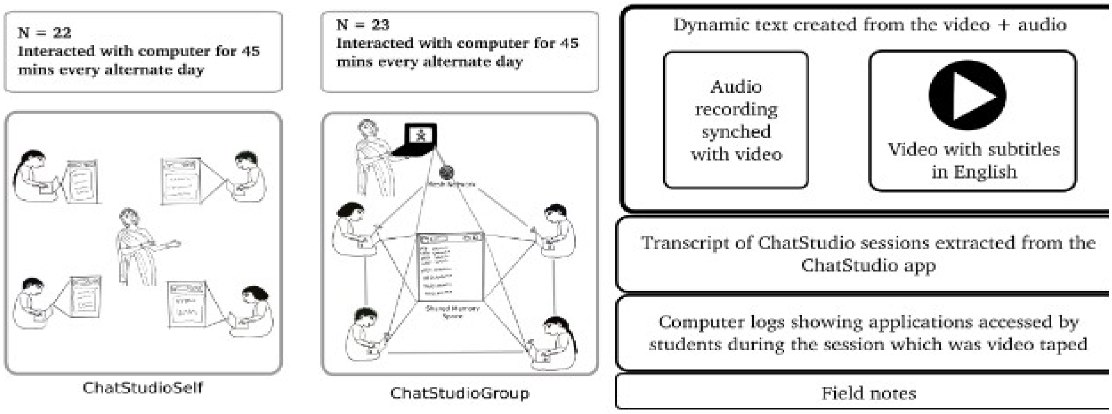

Figure 29: *Illustration of research design used in Study 3. The class of 45 students was divided into two groups, the ChatStudioSelf group (n=22) and the ChatStudioGroup group (n=23). Field notes, audio and video recordings, and computer logs were collected daily during the intervention. Focused group discussions with the students were held at the end of the intervention.*

The initial three days were used to build rapport with the students and the class teacher. I visited the school and played games with students for 45 min each day. Once the students were comfortable and were freely interacting, laptops were taken to the school. Each day, I used to charge the laptops, put them in a bag and take it to school. I could not keep the laptops in the school as there was no place to store and charge them. School administration had allowed me a 45 minute classroom-session towards the end of the school day. During that session, one group would stay in the class, and the class teacher would teach them as before, whereas the other group moved to another room where they got laptops, and I was the teacher. As a result of this arrangement, each group came to the computer session on alternate days. This arrangement also helped me as we only had 30 laptops. Each laptop was named after an element from the periodic table (e.g. Mercury, Zinc, etc.). This was done keeping students' privacy in mind. Students knew their laptop's name, and they would get the same laptop every time. On the day the CSS group was scheduled to use laptops, I used to disable the network and hide the ChatStudioGroup application. The next day, when the CSG group was scheduled, I used to enable the network and hide the ChatStudioSelf application. The teacher also used one OLPC laptop, and it also had a specific name.

The school was small and had a space crunch, so the computer session was conducted in any room available (see Figure 28). OLPC laptops are light, designed for rough handling, and could easily be carried by students. No Wi-Fi or wired network was required; laptops could create a local mesh network using radio technology anywhere in seconds. The initial three classroom-sessions with laptops were focused on letting students learn the essential functions. Functions like switching the laptop on and off, opening and closing an application, handling the cursor using the track-pad or mouse, using various buttons to take pictures or play games, connecting with a mesh network, joining a shared activity, and typing in Marathi. For these three classroom-sessions, both groups interacted with the laptop on the same days, in turns. For the rest of the days, each group came on alternate days. In these first few classroom-sessions, I noticed that the students had difficulty handling the cursor with the track-pad. I decided to use a mouse instead; that solved the problem, and students could navigate the screen easily. Once the students were familiar with the laptop, on day four, they were introduced to the ChatStudio application. Learning to play the ChatStudio game and learning to type fluently happened simultaneously. Students started using the ChatStudio applications from the fourth day onward. Table 3 describes the instructional environment and game-play used in two settings. Each group used laptops for 33–34 days and played ChatStudio games for 30 days. The first 8–10 min and the last 5 min would go into distributing/collecting machines and mice. So effectively, we used to get 30 min each day for actual game-play.

During the intervention, I used to carry a notebook to take notes and a voice recorder to record the audio. Logs from the computers were collected each day and saved on another computer. Logs contained meta-data and transcripts from the game and data about other applications available on the laptops. I could not video record all the classroom-sessions as the school administration did not give permission; however, they allowed the recording of one session of each group. A fellow research scholar came to school to record the video for two consecutive days. The camera was set up in one corner to record the entire class. The voice recorder was kept in my front pocket. The Voice recorder helped record the conversation between student and teacher that the video camera may have missed.

I also checked students' arithmetic proficiency. For it, I used an existing test developed by the Mathematics Education Group at Homi Bhabha Centre for Science Education, Mumbai, India. One example of questions from the test is shown below:

> *In the numbers given below, which is 'two thousand and sixty-nine'? (Mark the correct answer)*
>
> *a) 200,609, b) 2069, c) 200,069, d) 200,609*

The first test was done after dividing the students into two groups. Two groups were equivalent, and there was no significant difference ($p = 0.436$) in their test scores before intervention. After the test, the intervention started. The second test was done at the end of the intervention.

After the post-test, focus group discussions (FGD) were conducted with the students. For FGDs, each group was further divided into two sub-groups, resulting in 4 focus group discussion sessions. I thought that the conversation would be better facilitated in smaller groups. The students sat around a long table, and three researchers (including me) sat at three different positions on the table. All three researchers who participated in the FGD knew Marathi and had met the students earlier. Two separate audio recorders were placed at two ends of the table. In the FGD, students were asked about their experience using laptops, playing ChatStudio games, using other applications on the laptop, and connecting between regular and computer classes. Audio records of the focus group discussion sessions were transcribed for analysis.

Table 3: *Comparison of instructional environment and game-play*

ChatStudioSelf	**ChatStudioGroup**
At any given time, different students could be playing different game configurations	At a given time, the whole class is playing the same game configuration

Since students were playing different configurations, peer assistance was harder.	Since students were playing the same configuration peer assistance was easier.
Students assessed their game on their own, using the scorecard, or by talking to the teacher	In addition to self, scorecard, and teacher, peer-assessment was incentivized.
Students were rewarded with a Digital badge for accurate game-play	Students were rewarded with ranking on the digital scorecard, as well as the scores on the blackboard for peer-assessments.
After finishing, a student can reset the game for a new gameplay	After finishing, students need to wait till everyone finishes, and a new configuration is decided upon by the class.

6.2 Analytical Flow and Methodology[21]

To answer the first research question of whether there was a difference in students' engagement in the two settings, I drew on the app's log data and audio-video data. For the level of engagement, the log data was used to compare the number of students playing the ChatStudio app at least once on a given day . And the number of students checking in on other apps on the laptop at least once each classroom-session. Here, I am using "engagement" to mean simply if students were using the app and not any sense of deeper disciplinary engagement. The video recordings were synced with the audio and computer logs using timestamps. To understand patterns in the nature of students' engagement, I coded 15 minutes of video in each setting (CSS or CSG setting). The videos were recorded one week before the end of the intervention. I coded each interaction in each setting by (i) who were the participants in the interaction (student-student (S2S), student-teacher (S2T), student-machine

[21]Shaikh, 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.

(S2M), and teacher-machine (T2M)) and (ii) the nature of the interaction, such as play, discussion, exploration, seeking feedback, troubleshooting, etc. To infer the nature of the interaction, I used dynamic text that had a textual description of verbal, temporal, spatial, and kinaesthetic information from the video (Flewitt, 2006)). For any time segment, I coded all the students visible in the video. So, each time segment could have multiple codes resulting from co-occurring interactions (see Table 5). Additionally, in a particular interaction, a student, teacher, and the machine could be interactionally coupled. So, in any given time segment, the same interaction could contribute to more than one of the S2S, S2T, S2M, and T2M codes (see Table 5).

Based on the findings from this analysis, I created analytic memos of important events across the whole videotaped 45-minute classroom-session in each setting. Annexure-1 is an example of such a memo. It has a line number, date-time-stamp, the participant's name in the game with a specific colour, a description of the activity, and verbal utterances (see Table 4). I specifically looked to document events that were typical of a pattern in the participants' interactions or surprised me by violating some tacit or explicit assumption of mine. Most of the events I recorded were about self- or peer-assessment, requests for help, public recognition of success or failure, or contestation among participants.

Table 4: Section of an analytic memo. It had a line number, timestamp, user name, post on ChatStudio, description of actions, and transcript of verbal utterances.

Line	Timestamp	User	Post	Non-verbal	Verbal
20	17:26:01.897525	Mayur	31	Samita reports Sadanand 's mistake by raising hand (posted 23 instead of 24) mentioned above.	Samita: Dada Sadanand made a mistake; he wrote 23 instead of 24. T: ok.
21	17:26:04.598399	Nikhil	31	Sadanand hears Samita's claim and holds his head.	Bharti : (inaudible, probably counting numbers aloud)

22	17:26:05.790866	Krishna	31	Sadanand stares at his screen, still holding his head.	

To get at the second research question of disciplinary learning, I drew on the log data, focus group discussion transcripts, audio-video data from the classroom-sessions, and analytic memos of significant segments described above. Log data was used to compare arithmetic strategies students used to solve the game and win in each setting. I triangulated this with the focus group discussion from each setting, where participants shared what strategies they were using.

Table 5: Table showing an example of an utterance in the video that is coded for two codes (S2M and S2T).

Line	Timestamp	User		Post	Non-verbal
97	17:27:27.944054	Mayur	106	Chat log shows that Mayur has crossed the last number, for him it is 106. He stands up and jubilantly shouts.	Mayur P: Dada... 106... Dada 106. Amol: yes 106

Close analysis of segments of video of significant events in each setting using tools from interaction analysis (Jordan & Henderson, 1995) also provided insights into what strategies students were using and how they interacted with their peers. I attended to their body postures during these interactions, their gaze, gestures, facial expressions, loud celebrations and contestations, and the tone of their speech (for intonation markers and hedge words that indicate confidence, deferment, or confusion). To build explanatory stories for specific students' interactions, I also drew on the general history of their interactions during the classroom-sessions through a coarse-grained pass through the audio-video data. These stories gave me insights into differences in how students engaged in assessments of their (and, in the Group case, others') arithmetic, as well as towards the third research question pertaining to the construction of status and public displays.

In conjunction with the analysis, the specific form of the research question iteratively evolved (Bhattacharya, 2017; Maxwell, 2012). The final refined research questions were:

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

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

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

I operationalised general engagement as time spent on the arithmetic game, whether students were generally interested in playing the game, and what kinds of activities were they involved in during the intervention. For arithmetic use, I looked at the types of addition problems students were solving, the strategies they were using, and how they assessed their and others' performance. For status construction, I again looked at episodes of self- and peer-assessment, conflicts and contestations, public celebrations of success, and other significant S2S interactions to see how students were recognized as successful by the teacher or peers and how they were positioned as mathematically competent or not in interactions. In many cases, it is difficult to pin point causal mechanisms to answer the "why" question. I am also not orienting to the presence or absence of SMS as the only difference between the settings. Instead, as described above, there are a number of digital, instructional, and social (interactional) differences between the two settings. Many of these differences are prompted by the presence/absence of SMS. The explanations I build in this Chapter show how the different configurations of digital, instructional, and social-interactions together produce the differences in observed patterns. The presence or absence of SMS is part of my explanation, but so are the affordances and constraints of the arithmetic game and of the instructional environment. Thus, my findings aim to shed light on the influence of SMS, situated within a classroom environment, in the context of an arithmetic game, on the students' social, affective, and disciplinary engagement with arithmetic.

I want to emphasize that I divided the classroom into two groups so that my analysis could determine the differences in the interactional aspects of the two settings. Crucially, most of my quantitative measures are also not about measuring "outcomes" but instead getting a sense of differences in the patterns of interactions between the two settings. Then, I pivot to qualitative methodologies to analyse chat-data and video-data from the two settings to illustrate how the interactions played out differently. Here, I present a detailed analysis of specific episodes that help elaborate on how the classroom norms and specific technology features entangled with students' interactions to produce different coherences in the two settings. In this sense, each of the two "conditions" in my study constitutes a "case," and my analysis illustrates how these two cases lead to different configurations of contextual features and interaction patterns. Specifically, the "Self" setting provided a point of reference that brings into relief interaction patterns, norms, and technology features that I observed in the "Group" setting. Research designs similar to mine have also been used previously (McCoy & Lynam, 2021; Nguyen, 2022; Pargman, 2003).

6.3 Findings[22]

Before diving into the process data, I checked students' performance on the arithmetic proficiency test. As mentioned earlier, the tests before the intervention showed no significant difference in the two groups (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).

6.3.1 Comparison of Engagement across the two settings

To check the student's level of engagement (research question 1) with ChatStudio, 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 classroom-session in each setting. This was used as a coarse-grain measure of the level of students’ engagement of the students. A difference was observed in the engagement level in the two settings. In Figure 30a, we can see that at the beginning of the intervention, students from both settings engaged with the game. However, as time passed, the engagement

[22]This section is published in: Shaikh, 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.

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. Figure 30b 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.

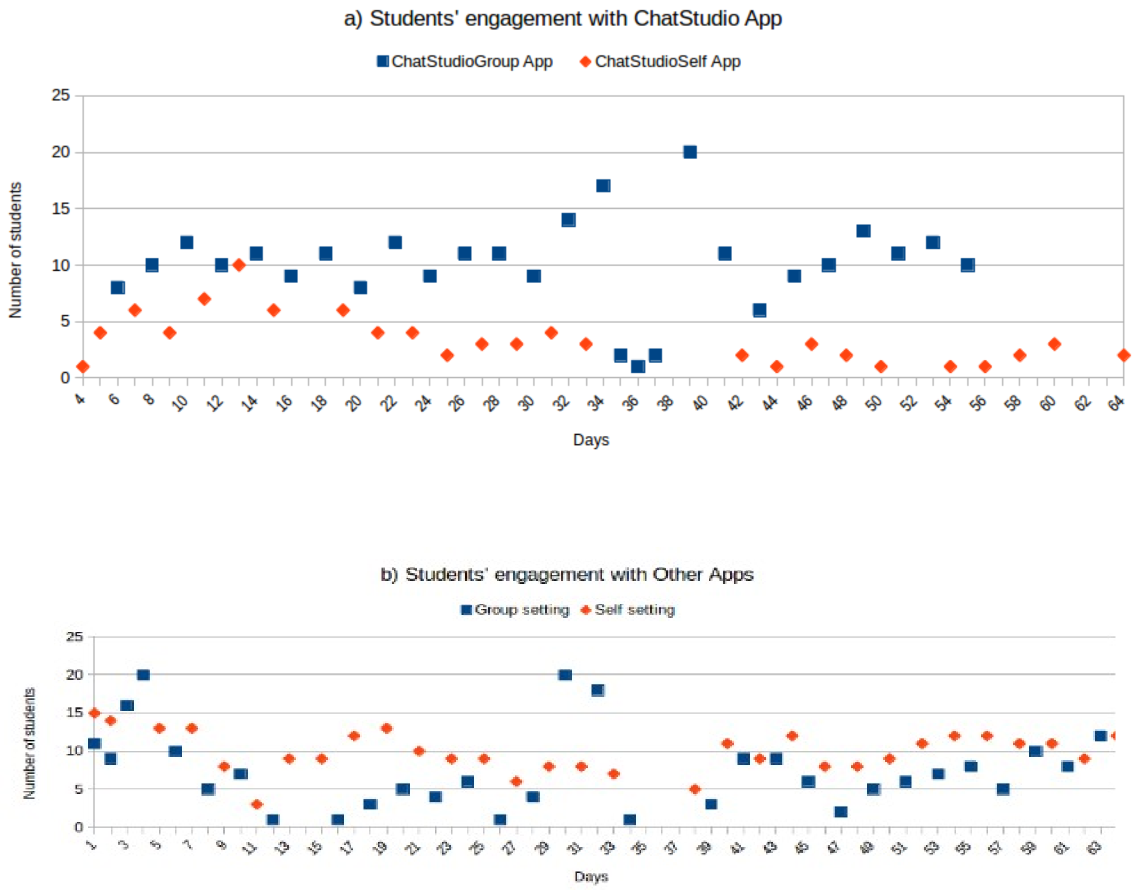

Figure 30: *(a) Comparison of students' engagement with ChatStudio in Self (N=22) and Group (N=23) settings; and (b) comparison of students' engagement with other application during the entire intervention.*

Next, I checked the interaction pattern in both settings. As I note in the methods, I coded the nature of interactions between students, teacher, and machine in each setting for 15 minutes of video. Recall that I was the “teacher” during these interventions. Out of those 15 minutes, the first 5 minutes in both settings were spent on distributing the machines and class management. So effectively Figure represents interactions that happened in the later 10 min of the selected video segments.

Figure shows the number of student-student, student-machine, student-teacher, and teacher-machine interaction events in each setting. The pattern of interactions in the two settings was different. In the CSS setting, the majority of events were student-teacher interactions. There were a few student-machine and teacher-machine interactions and fewer student-student interactions. In the CSG setting, by contrast, the number of interaction events were distributed more equally among students, teacher, and machines. This observation was also triangulated with the data from the focus group discussions and the field notes. In the focus group setting, students from the CSS setting mentioned that they approached the teacher for every issue. However, students from the CSG settings mentioned that they approached peers as well. The total number of interactions in the CSS setting was also much higher than that in the CSG setting (89 versus 54), while the length of interactions was typically longer in the CSG setting.

Inspecting the video to look at the content 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 (IRE pattern), where a teacher is the main 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 game-play. Later, I present a few vignettes of such interactions.

Interactions of students and teachers with the machine were analysed in both settings. From Figure ,we can see that, in the CSS setting, there were relatively more teacher-machine interactions as compared to student-machine interactions. The pattern was reversed in the CSG setting. In the CSS setting, many of the teacher-machine interactions were during evaluations of students’ work, which I have noted was a dominant form of interaction in that setting and outnumbered such interactions in the CSG setting. In the CSG setting, there were many more student-student interactions. Student-student interactions in the CSG setting often also involved student-machine interaction events such as looking at the computer screen, interacting with the computer screen (e.g., scrolling), pointing to some number on the screen, or referring to it in talk. In these interactions, the screen was entangled with students’ arithmetic (self- and peer- assessment) and argumentation practices. Fine timescale analysis of some of these interactions, presented later, helped me flesh out detailed stories of this entanglement. Fine timescale analysis is a method inspired by Segler (2007), which involves closely examining and tracking rapid changes in a short segment of a video, allowing for a detailed exploration of cognitive developments and learning processes over a brief time-frame.

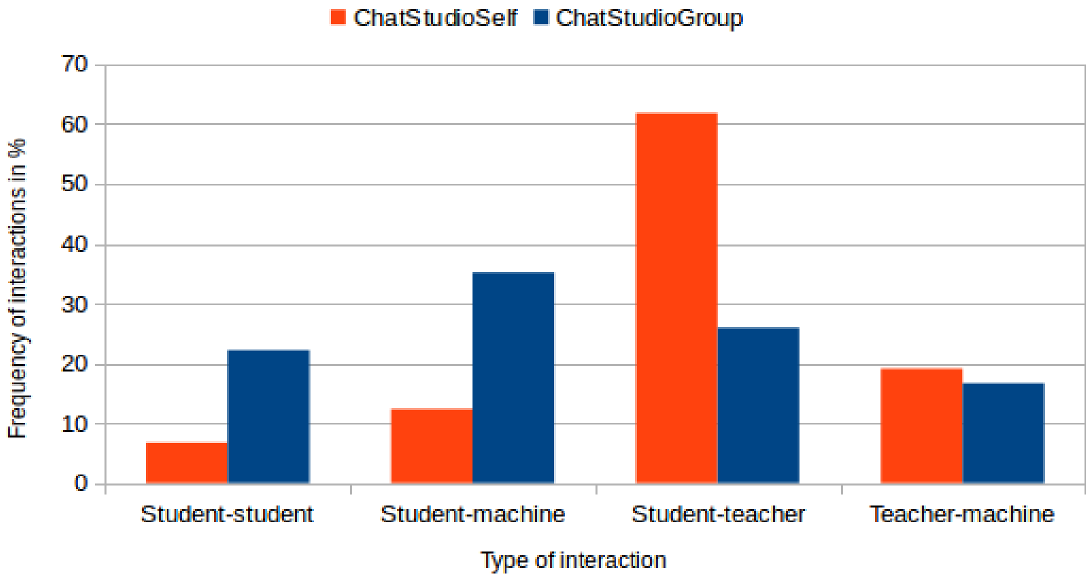

Figure 31: *Graph showing number of different interaction events during a 10-minute segment from each setting*

6.3.2 Comparison of game-play strategies across the two settings

In terms of the learning of arithmetic (research question 2), I looked at what kinds of number pairs students were choosing during game-play, and what kinds of strategies they were using to advance through the game.

The ChatStudio game (both settings) had three difficulty levels and one custom number pair option. I see a difference in the difficulty level chosen and the selection of number pairs in both groups. The computer logs show that the CSG group tried 42 different number pairs, whereas the CSS group tried only 14. For example, from the screen video recording, I document how a couple of students in the ChatStudioSelf setting opt for a customized number pair with one as a starting and one as a stepping number. It is the most basic possible number pair in the game. Looking at the computer logs of students in the CSS setting, I found that many students in the ChatStudioSelf setting frequently opted for customized number pairs and chose simple number pairs, such as (10 and 10) or (20 and 20). Many students in the CSS setting repeatedly selected the same 'number pairs,' to my surprise. Table 6 shows examples of two students and the selection of various number pairs in successive game sessions. In comparison, the students in the CSG setting opted for a variety of number pairs. In the CSG setting, there were 21 pairs that were selected just once, 16 pairs that were selected twice, 4 pairs 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.

Table 6: *Part of the computer log showing the selection of number pairs (columns 6 and 7) by two students in successive game sessions.*

Student name	Date	Time	Accuracy	RT	start Number	Second number	mode	steps	mistakes	avg_response_time	difficulty_level
Sanjana	03/02	05:17	100	38.188	10	10	Addition	4	0	9.547	Changed_Numbers
Sanjana	03/02	05:24	100	26.45	20	20	Addition	1	0	26.45	Changed_Numbers
Sanjana	03/02	05:29	87	89.178	3	3	Addition	15	2	5.945	Easy
Sanjana	05/03	05:01	100	33.222	10	10	Addition	4	0	8.306	Changed_Numbers
Sanjana	10/02	04:55	100	151.012	5	5	Addition	9	0	16.779	Changed_Numbers+
Sanjana	10/02	04:56	100	26.693	10	10	Addition	4	0	6.673	Changed_Numbers
Sanjana	10/02	04:58	100	50.753	20	20	Addition	1	0	50.753	Changed_Numbers
Sanjana	10/02	05:01	100	41.639	10	10	Addition	4	0	10.41	Changed_Numbers
Sanjana	10/02	05:02	100	40.676	20	20	Addition	1	0	40.676	Changed_Numbers
Sanjana	10/02	05:05	100	156.299	10	10	Addition	4	0	39.075	Changed_Numbers
Sanjana	10/02	05:12	100	32.427	20	20	Addition	1	0	32.427	Changed_Numbers
Sanjana	12/02	05:26	100	33.523	10	10	Addition	4	0	8.381	Changed_Numbers
Sanjana	12/02	05:27	100	26.164	20	20	Addition	1	0	26.164	Changed_Numbers
Sanjana	12/02	05:28	75	34.816	10	10	Addition	4	1	8.704	Changed_Numbers
Sanjana	16/02	05:00	100	37.771	10	10	Addition	4	0	9.443	Changed_Numbers
Sanjana	16/02	05:01	100	22.403	20	20	Addition	1	0	22.403	Changed_Numbers
Sanjana	16/02	05:01	100	15.228	20	20	Addition	1	0	15.228	Changed_Numbers

Sanjana	16/02	05:01	100	22.26	20	20	Addition	1	0	22.26	Changed_Numbers
Sanjana	16/02	05:02	100	59.689	20	20	Addition	1	0	59.689	Changed_Numbers
Sanjana	16/02	05:05	100	23.031	20	20	Addition	1	0	23.031	Changed_Numbers
Sanjana	16/03	05:23	100	92.979	10	10	Addition	4	0	23.245	Changed_Numbers
Sanjana	16/03	05:24	100	21.288	20	20	Addition	1	0	21.288	Changed_Numbers
Sanjana	16/03	05:26	100	19.186	20	20	Addition	1	0	19.186	Changed_Numbers
Sanjana	16/03	05:29	100	27.601	10	10	Addition	4	0	6.9	Changed_Numbers
Sanjana	16/03	05:30	100	35.369	10	10	Addition	4	0	8.842	Changed_Numbers
Meena	19/12	05:02	100	53.308	10	10	Addition	4	0	13.327	Changed_Numbers
Meena	19/12	05:08	100	251.396	1	1	Addition	49	0	5.131	Changed_Numbers
Meena	19/12	05:09	100	31.013	10	10	Addition	4	0	7.753	Changed_Numbers
Meena	19/12	05:10	100	49.659	10	10	Addition	4	0	12.415	Changed_Numbers
Meena	19/12	05:11	100	43.369	20	20	Addition	1	0	43.369	Changed_Numbers

There was also a difference in the strategies that students used for game-play. 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. 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 strategies that drew my attention was the use of multiplication tables for deciding number pairs as well as the 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 game sessions, as compared to only 3 students in the CSS setting. The elementary school mathematics curriculum in India requires students to learn multiplication tables, and many students learn them by rote. I cannot tell which students first started using the multiplication strategy, but the strategy soon spread. In focus group discussion, students in the CSG group explicitly noted that they “used multiplication tables to solve addition problems.” They also demonstrated a functional understanding of the strategy. In the focus group discussions, students from the CSG setting confidently insisted that they could only use the multiplication tables when the starting and stepping numbers were the same and not in other situations. In comparison, during focus group discussions with students in the CSS setting, they were unsure about using the multiplication tables. For example, in one discussion, a student noted that the multiplication strategy can be used for all number pairs, and then quickly switched to saying that the tables cannot be used for any number pairs.

I cannot draw out a full causal mechanism for these differences. However, field notes of intervention classroom-sessions, and video data point to a configuration of factors in each setting that could have contributed. In either setting, there was a need for speed; however, in the CSS setting, students were competing with their own prior completion times, while in the CSG setting, students were competing against one another in the same game-play. One could imagine why it might be attractive for someone to try the same number pair again in the CSS setting to see if they can beat their own prior timing. Another difference was that the students in the CSS setting chose their number pairs individually, while those in the CSG setting chose a common number pair for the whole class to compete. This group discussion in the CSG setting led students to choose a more varied set of number pairs and not repeat the same combinations. This raised the arithmetical difficulty of doing fast additions in the CSG setting as compared to the CSS setting. In spite of the increased difficulty, most students in the CSG setting also finished the games with a reasonable accuracy level.

Field notes and focus group discussions suggest that the shared memory space (SMS) supported students in completing these calculations. Many students reported looking at the screen for what other students were typing when they were struggling. However, as I show in the subsequent sections, students drew on academic status and friendship to judge which of the numbers from the screen to take up in continuing their own game, suggesting that they were not mindlessly copying. Field notes and video analysis suggests that the assessment and reward structure differences in the two settings also contributed to the choice of the number pairs. The assessment in the CSS setting was mainly an interaction between an individual student and the teacher, who evaluated the game and gave the student a high-five for successful completion (along with the machine generated badge shown in Figure 32). The teacher was having to support multiple students at any given time, and was unable to attend to the level of difficulty students were attempting or comment on the repetitive choice of number pairs. In the CSG setting, by contrast, the assessment itself was distributed since students could see each others' game-play and celebrate or contest outcomes collectively. In the next sections, I describe these interactional differences between the two settings.

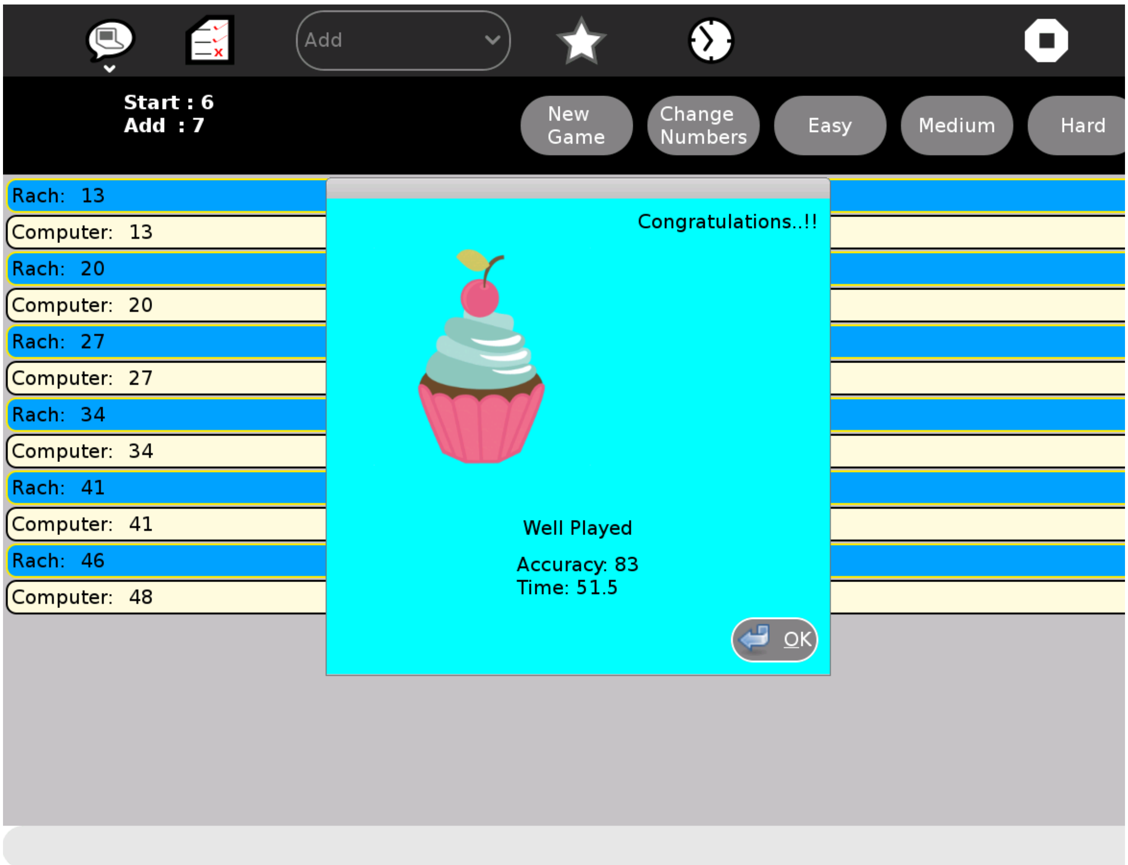

Figure 32: *Screenshot showing digital badge students received at the end of a game session is ChatStudioSelf version of the game.*

6.3.3 Assessments, Status, and Relationality in interactions

One of the things that jumped out at me during analysis was that many of the student-student and student-teacher interactions were structured as assessments of arithmetic. In these moments, arithmetic assessment, academic status, and social relationalities were co-constituted. However, the CSS and CSG settings differed in how these moments were configured in each.

In the CSS setting, the dominant mode of assessment was students reaching out to the teacher. Analysis of selected episodes showed that many student-teacher interactions had a typical pattern in the CSS setting. A student playing the ChatStudioSelf game calls the teacher; the teacher goes and inspects her work. The teacher either gives her feedback or cheers her up by encouraging her. Here I highlight an episode to illustrate how getting the teacher's approval was important to the students in the CSS setting before moving on. In this episode, a female student, Sonali[23], did not proceed to the next game session of the game after finishing a game successfully. She calls the teacher to show her the badge that had appeared on her screen when she finished that session of the game (Figure 33). However, while waiting for the teacher to come to her desk, the badge disappeared. She pressed some buttons until the badge reappeared. The badge disappeared again, twice, and Sonali brought it back twice and waited for the teacher. She moved to the next activity only after showing it to the teacher and getting her approval. This suggests that to Sonali, in the context of this activity in that classroom, knowing that she had correctly solved that game and getting the digital badge from the system was not sufficient; the teacher's approval was also necessary for moving on to the next game. Field notes taken by me (I was also the teacher) support that this way of ending the game with the teacher's approval was common in the CSS setting.

[23]Pseudo-names are used for all the students.

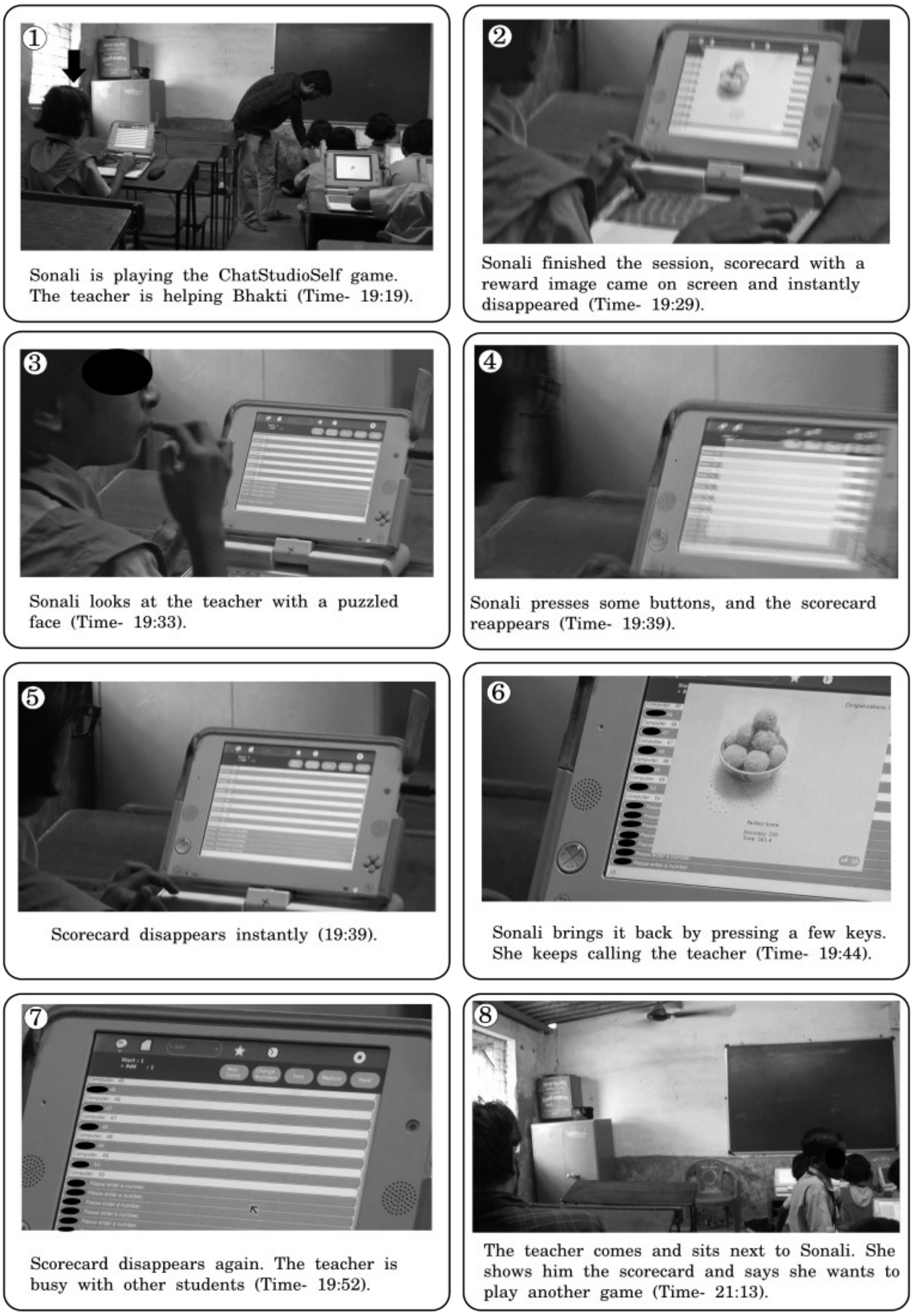

Figure 33: *Chronologically arranged snapshots of the classroom scene and Sonali's computer screen to illustrate assessment interactions between a student, Sonali, and the teacher.*

There were also instances of self-assessment in the CSS setting. For example, in another episode, Sonali typed a number but paused before posting it. She erased the number, and typed another number and posted that. It is not easy to say what went into her mind. However, it is plausible that the visible log of the previously typed numbers supported her in error correction.

In contrast, in the CSG setting, there were lots of student-student interactions in conjunction with student-teacher interactions. The involvement of the teacher in the assessment events was also different. In addition to checking individual work, or technical troubleshooting, the teacher was also involved in the peer-assessments that were taking place during and at the end of the game. There were also many more instances of self-assessment in the CSG setting. Partly, I think that the higher number of these self- and peer-assessment events was due to the incentive structure in this setting, where students had an incentive to report on errors by self and others. The purpose in presenting some episodes of this is to illustrate the dynamics of interactions between students, teacher, and machine in the CSG setting.

The illustrative segments come from a game in which the starting number was 17, the stepping number to be added was 7, and 100 was the threshold to cross (see Table 7). The correct sequence of numbers in this game would be 17, 24, 31, 38, 45, 52, 59, 66, 73, 80, 87, 94, 101.

Within a few seconds of the game starting, a male student, Sadanand, posts 23. For this step, 17+7=24 is the correct answer. And within 3 seconds of Sadanand's posting, a female student, Samita, calls out to the teacher announcing that Sadanand has made a mistake. In Table 7, I show the time-coordinated computer log and video-observations leading up to Samita calling out Sadanand's error. I note that Sadanand's post of 23 was sandwiched by other students posting 24. Also note that instead of addressing Sadanand, Samita points out the error to the teacher. The computer log shows that within 10 seconds of this, Sadanand posts 24.

Table 7: *Part of the time log showing the series of events leading up to Samita calling out Sadanand's mistake*

Line	Timestamp	User	Post	Non-verbal	Verbal
13	17:25:56.931586	Mayur	24	Samita uses her fingers as a support while calculating	
14	17:25:57.177407	Amol	24		
15	17:25:57.970794	Sadanand	23		
16	17:25:58.315132	Nikhil	24	Samita types a number, Just before clicking "enter," she looks at screen, her face shows shock	
17	17:26:00.243188	Samita	24	She posts her number and immediately stands and speaks loudly	Samita : Dada, Sadanand made a mistake
18	17:26:00.704793	Krishna	24		Samita: he wrote 23 instead of 24 T: ok
19	17:26:01.419337	Amol	31		
20	17:26:01.89752	Mayur	31		

5

What this suggests is that at least some students were monitoring the screen for the numbers posted and errors even before finishing their own game. This monitoring of the screen for numbers was also evident in events of self-assessment. Unlike the CSS setting, however, in the CSG setting students often announced their own mistakes to the teacher. This was perhaps prompted by the incentive structure (students received points for reporting errors) for reporting errors. In about 3 minutes of gameplay for this particular game, two students reported their own errors to the teacher. In one case, a male student, Nikhil, posts 522, stops, and calls to the teacher:

Nikhil: Dada...wrote 522 instead of 52

T: hmm who?

Nikhil: Me

T: hmm ok

T: start posting from 52 onwards

Nikhil posts 52 and continues. Within seconds, another male student, Krishna, announced to the teacher that he made a mistake:

Krishna: Dada there is a mistake.

T: who did?

Krishna: I did, I wrote 69 and then 66.

T: ok go ahead complete the rest of the steps.

Field notes support that, in the CSG setting, it was common for students to publicly report on the errors made by themselves or by others, even before they have finished the game. However, at the end of the game, once some students have crossed the finishing number, there were more of such error reporting events. As more students cross the finishing number, more of them joined in finding and reporting errors. During these events, students would often scroll the screen to see the computer log of colour-coded numbers posted by the students.

I next present a detailed analysis of interactions at the end of this particular game to illustrate some of the dynamics amongst students, teacher, and machine. The episode starts when Amol stands up at his place in celebration, declares that he crossed the last number, and says it is '106'. However, as soon as Amol declares it to class, Samita counters, saying he is wrong as he wrote '1006' instead of '106'. Soon, Mayur also claims that he crossed the last number, '106', and starts clapping with a happy face. He also points out that Amol made a typo and wrote '1006' instead of '106'. Then Amol says Samita made a mistake; she wrote '101' instead of '106'. That means Samita has crossed the last number, but unlike Amol and Mayur, she did not celebrate publicly. Computer logs confirm that she did cross the last number, and as per her calculations, it is '101'. Amol tries to explain to the class and teacher why Samita is wrong, and the answer is '106', not '101'.

Meanwhile, another student, Sadanand, declares that he crossed the last number, and it is '103'. Soon a few more students reach the last number, and confusion in the class increases. For Shushma, it is '100'; for Mahesh and Amol, it is '102'. It seems nobody is sure what the last number is. A few students look towards the teacher, but he is also unsure as the computer randomly generates the number pairs, so he will have to calculate and find out. He tries asking another person in the class who is recording the video but realizing that she might not be able to help, he goes near the blackboard and writes numbers on it after calculating. After confirming, he tells the class that Samita is correct and the last number is '101'. While the teacher was doing calculations, Amol was standing near him and pressing that it was he who was correct; it was '106'. Even after the teacher says that Samita is correct and the last number is '101', a few students seem to contest that. Mayur and Amol still feel that it is '106'. Amol says their last number (106) is correct, as he did every addition by counting with his fingers. After the teacher's confirmation, Samita is confident and points out that Shushma and Sadanand made mistakes; Nikhil also accepts the teacher's last number and points out that Sadanand made a mistake.

Meanwhile, everyone crosses the last number, and the system automatically generates a scorecard. Students can see that the teacher correctly said Samita's calculation was proper. The combined authority of the teacher and computer algorithm finally settles the confusion in the class.

Some of these dynamics perhaps were also influenced by the positionality of the teacher. For this class, I was the teacher, even though I was not a regular teacher, and I interacted with each group for a limited time on alternate days. I, as a temporary teacher, still enjoyed the position of power due to the school administration presenting me as a temporary teacher, my age, and my association with a research institute. However, I also differed from other teachers in the school in some aspects. Students did not call me teacher or sir. They called me 'Dada,' a Marathi word for elder brother. Maybe due to my non-formal position in the school and my age. Its effects could be seen in how students interacted with me. Contrasting the observations from regular classes show that students talked freely in ChatStudio class; there is also more noise. The difference could be seen in an episode in the video, where the regular teacher of the students comes to the ChatStudio room to talk to a few students regarding some work; as soon as the teacher enters the class, suddenly, everyone goes quiet. However, I was the teacher in both settings but only in the CSG setting do we see students confidently arguing their case.

6.3.3.1 Student’s attitude

I take you back to the episode presented in the above section. In this section, I am focusing on a female student named Samita (see Figure 34). I want to point out how different students behaved differently when finishing the game. For example, when a male student Amol announces that he won, he leaves his seat and comes out shouting. However, when Samita crosses the last number, she does not announce or celebrate like Amol or other male students. Samita was a shy student. I also took some time to build rapport with her. In contrast, Amol was not shy and showed emotions openly. The difference between Amol and Samita could also be due to the culture. I noticed a difference in how male and female students conducted themselves in the class. Male and female students sat separately, even in the ChatStudio class, where I was the teacher and did not force gender-based seating arrangements. Female students were much more soft-spoken than males; male students could be seen arguing and fighting in class. Male students showed much aggression and celebrated loudly, whereas female students quietly celebrated by smiling or high-five-ing with neighbours. Even though students are in grade 4th and around 9 to 11 years old, they could be seen behaving as per conventional socio-cultural gender norms. These norms (roles) are part of the Indian culture, specifically the local culture of a Maharashtrian family with a low socio-economic background (Bhattacharjee, 2021).

The next critical moment in the episode was when students were auguring about the correct final number. As nobody is sure, students approach the teacher. He calculates and tells the class that Samita is correct; the final number is '101'. At this moment, we see Samita deviating from her observed behaviour so far. Even though she does not celebrate, she soon points out the mistakes made by others. At one point, like male students, in excitement, she even tries to leave her seat and come out in the open, but as she is sitting in the middle struggles to come out. So far, her interactions were with the teacher or female students seated next to her. However, at this moment, she, for the first time, directly engages with two students from the opposite gender. She points her finger at a male student, tells him about his incorrect calculation, and explains why she is right.

In this episode, Samita 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 and teachers, when the teacher declared that she was correct, we saw her self-confidence boosted by her expressions.

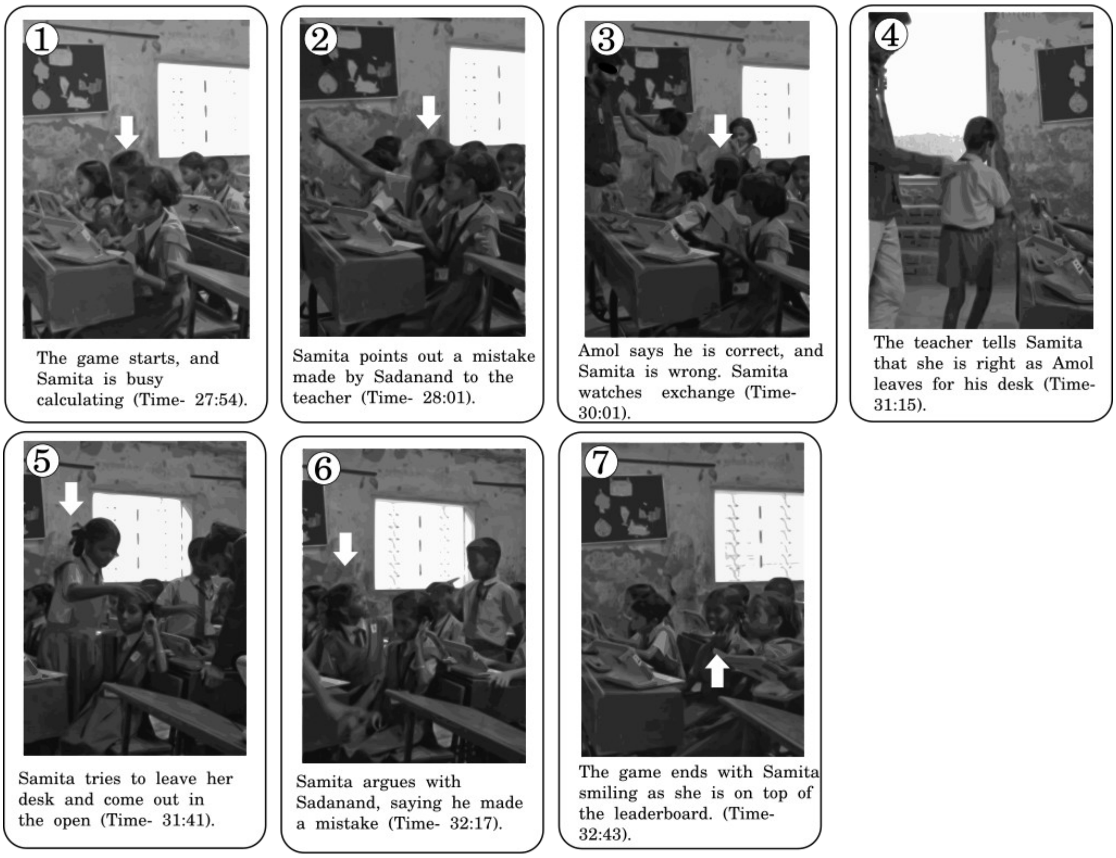

Figure 34: *Chronologically arranged snapshots of the classroom scene showing the sequence of events that lead to boost in Samita's confidence.*

6.3.3.2 Status, Trust, and Friendship

In the final vignette, I show how pre-existing relations amongst the students influenced who they looked to for help. The episode (see Figure 35) 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 on an adjacent desk. Instead, Krishna goes to Aakash, even though Aakash is not playing the game in session 1 (See Figure 35). He 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.

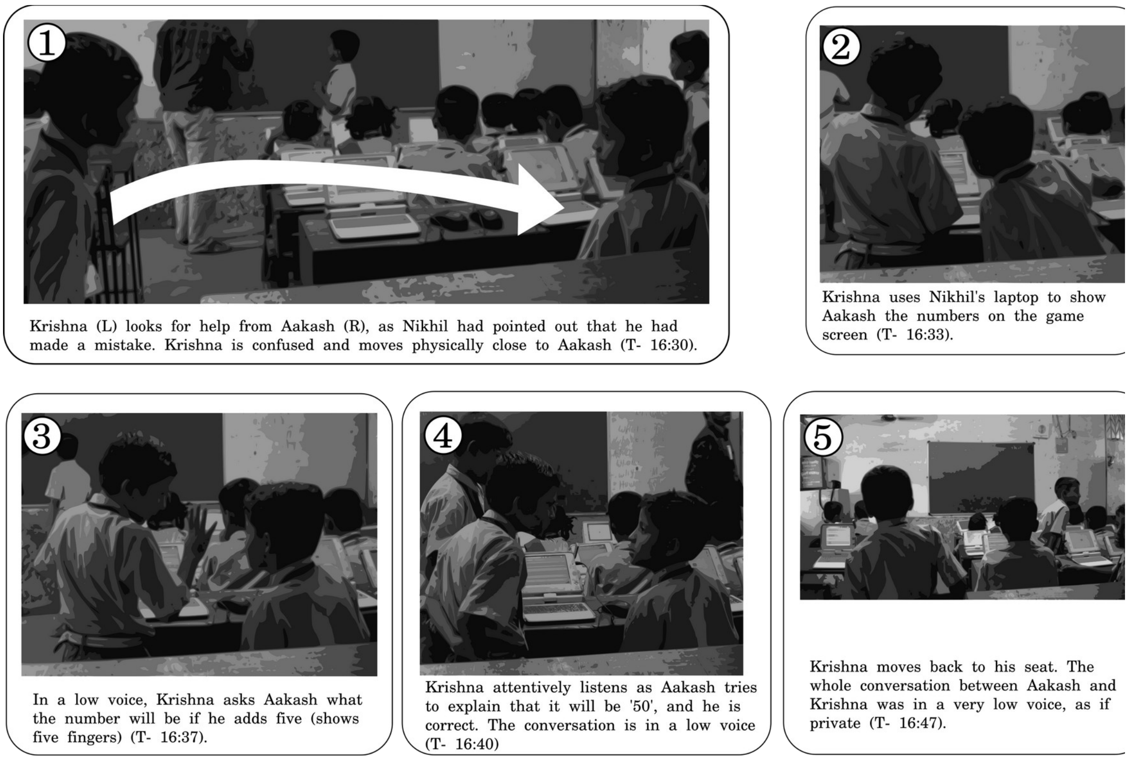

Figure 35: *Chronologically arranged snapshots of the classroom scene showing the interactions between Krishna, Akash and Nikhil.*

6.4 Conclusion and Discussion[24]

The study was conducted to examine the role of SMS in learning. This study confirmed what others (Lomas et al., 2017) had reported: simple rule-based games can be engaging and motivating. In agreement with other studies in the literature (Plass et al., 2013), I also saw a

[24]This section is published in: Shaikh, 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.

higher level of engagement when the digital interface and classroom norms encouraged peer interactions and peer assessment.

I also 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, 2003b). 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; however, our 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 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. (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 (Rada, 1994) in the ChatStudio game as one could play the game by following and copying someone's numbers. However, one needs to think and reason to assess others' work.

The students in both settings 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? I think both versions of ChatStudio satisfy two basic needs of students, as Deci and 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 a 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 suggests that along with the knowledge level of the peer/adult, the relationship with the learner also matters. 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 also can lead to the development of trust (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). Peer conversations can contribute to the construction of relationships.

Chapter 7: Discussion and Implications

The final chapter delves into extensive discussions revolving around the research studies conducted throughout this thesis. All of these studies were driven by the central question: **What role does a shared memory space (shared screen) play in supporting classroom interactions and disciplinary learning in a computer-supported primary school classroom?** I conducted three studies to address this question. Study 1 explored the potential of an instant messaging environment for teaching arithmetic to primary school students. In Study 2, I designed and evaluated two versions of a digital game aimed at facilitating arithmetic learning. Study 3 delved into investigating the role of shared memory space (SMS) in supporting social interactions and disciplinary learning. The findings from these studies indicate that an instant messaging environment can effectively support arithmetic learning among primary school students. Moreover, social interactions within the game context induce affective changes in students, as evidenced in Study 1. Study 3 underscores the significance of shared memory space in fostering disciplinary learning, increasing engagement, shaping attitudes, fostering supportive relationships, and influencing power dynamics. These findings hold implications for designing instructional games, particularly for mathematics learning, and provide valuable insights for learning scientists and educational researchers.

6.5 Summary of Work

The larger problem this thesis identified was inadequate social interactions in school classrooms. Out of multiple available approaches to make classrooms interactive, I adopted networked computers to support social interactions. The approach is popularly called Computer-Supported Collaborative Learning (CSCL). Within the CSCL, I located a less explored area - the role of shared memory space (shared screen) in learning in a co-located primary mathematics classroom. I conducted three research studies that tried to answer the following questions:

1. Can an instant messaging environment (Chat Activity) be used to teach arithmetic skills (RQ1)?

2. If yes, how does learning happen, and what features help in learning (RQ2)?
3. How does a shared memory space (shared screen) in a networked computational game environment influence students' engagement (RQ3)?
4. How does a shared memory space (shared screen) in a networked computational game environment affect disciplinary learning and practices (RQ4)?
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 (RQ5)?

Study 1 was conducted to answer the RQ1 and RQ2. In study 1, I studied a case of a primary school classroom learning arithmetic through playing simple number games using an instant messaging environment. The key outcomes of this study were-

- An instant messaging environment can be used to play multiplayer number games, and it can lead to learning arithmetic skills.
- Disciplinary learning, social interactions, and students' public display of emotions seemed to be connected.

Based on the results of Study 1 and additional observations made during the study on how students interacted with the system, I hypothesised that the SMS is one of the central features the Chat activity game, and it played a role in both disciplinary learning and affective changes. To probe this idea further, I decided to investigate the role of SMS further through a systematic study. RQ3, 4 and 5 were formed to test this hypothesis in a systematic manner. Designed and conducted Study 2 and Study 3 to answer RQ3, RQ4 and RQ5.

In Study 2, I developed an application based on the experience of Study 1 and created two versions of it. Both versions were similar, except one had SMS, and the other was without it. I created two versions to have two cases that can be contrasted to tease out the role of SMS in disciplinary learning, engagement, and construction of status and emotions. The key outcomes of the analysis of data from Study 2 and Study 3 were:

- In the classroom with SMS, the pattern and context of interactions were different from the classroom without SMS. The classroom without SMS was similar to a traditional classroom, whereas, in the classroom with SMS, there were a lot more student-student interactions.

- Having SMS in the class altered the learning process. Offloading and instant sharing of representations enabled interactions that supported assessment and peer learning. These interactions also supported the construction of social status and relationality among students. It could be seen through the variations in public displays of emotion by students.

6.6 A brief summary of findings

6.6.1 Digital tools that support learning could be as simple as a chat environment

This thesis investigated the use of chat environments or instant messaging platforms as tools to support learning. While the use of chat environments has been extensively studied in the context of remote learning, this thesis specifically focused on their use in co-located settings.

Notably, a simple tool like a chat environment proved to be highly effective in supporting learning within a co-located setting. Cheung and Slavin (2013) in their meta-analysis note that simpler applications often provide clearer and more focused learning experiences for students, leading to better learning outcomes. By focusing on chat environments' development, utilisation, and role, this thesis systematically examined their impact on the learning process.

Through a comprehensive analysis comprising three distinct but related studies, the research shed light on the potential of chat environments in facilitating learning and fostering interactive classrooms. The results from these studies consistently demonstrated the effectiveness of chat environments in supporting learning and creating an engaging co-located classroom environment.

These findings aligned with previous research emphasizing the advantages of collaborative learning environments over individual learning settings for disciplinary learning. Notably, the Virtual Math Team project by Stahl et al. (2006b) and colleagues successfully employed instant messaging environments to support student interactions in high school mathematics. Similarly, these environments have been utilized to teach specific concepts in biology and physics. However, a need for research existed concerning using instant messaging environments for teaching mathematics in regional languages at the primary school level. This study addressed this need by investigating the efficacy of ChatStudio in this specific Marathi speaking context.

6.6.2 Competitive social games with simple rules can be engaging and motivating

The existing literature acknowledges that both solo and social settings have their own strengths in influencing the learning process. Solo games are recognised for their benefits in problem-solving practice and individual fluency development (Mullins et al., 2011). On the other hand, social games foster collaboration, discussions, knowledge co-construction, and motivation (Hausmann et al., 2004; Linnenbrink-Garcia et al., 2010; Rogat et al., 2013).

The three studies described in this thesis contribute to this understanding by focusing on the integration of instructional digital games and their impact on student engagement and learning. The findings suggest that the social game designed in these studies was engaging, led to more peer interactions and facilitated effective learning. Specifically, Study 1 and Study 3 demonstrated that the game design successfully captured student engagement and enhanced their learning experience.

While the existing literature recognises the complex interplay between solo and social settings, the studies presented in this thesis provide valuable empirical evidence that supports the notion of social games being more engaging and motivating for students. These findings contribute to the understanding of how game design and the competitive nature of social game-play can positively influence student engagement and learning outcomes. Understanding the interplay between sharing, engagement, and learning requires further examination to gain a comprehensive understanding of the dynamics and effectiveness of solo and social educational games in diverse learning contexts.

Research suggests that both competitive and collaborative social games have positive impacts on learning outcomes in primary school settings (Johnson et al., 1981; Pareto et al., 2012; Shaikh et al., 2013). Competitive games foster motivation, engagement, skill development, problem-solving, and cognitive abilities (Cagiltay et al., 2015; Lam, 2004), but precautions should be taken to avoid negative outcomes. Collaborative games promote cooperation, teamwork, communication, and higher-order thinking skills (Craig et al., 2019). Combining competitive and collaborative elements can be beneficial in specific contexts (Dicheva et al., 2015; Sung & Hwang, 2013). The digital game used in the studies in this thesis had a competitive game-play, and the findings corroborate what the literature in this area says. However, it is important to note that user behaviour can influence the nature of gameplay. Observations from Studies 1 and 3 indicate that even in competitive gameplay, primary school students often collaborate and provide help.

Study 1 sheds light on the significance of game simplicity. Similar to what Lomas et al. (2017) had reported, this study demonstrated that when game rules were kept simple, students actively participated and engaged with the game, even in the absence of direct supervision from the teacher. This finding emphasized the importance of designing games with intuitive and easily understandable rules to encourage student autonomy and involvement.

Furthermore, Study 3 explored the influence of peer assessment on student attitudes. The results indicated that when students were aware that their peer assessment efforts would contribute to their final scores, they exhibited a positive attitude towards the assessment process. Chen (2021) and Hoang et al. (2022) had reported similar results. Which suggested that incorporating meaningful incentives and recognizing the value of peer assessment could foster a more favourable and enthusiastic approach among students (Phielix et al., 2009).

6.6.3 Classroom Norms Can Play a Significant Role in Creating Interactive Learning Environments

Research emphasises the significance of positive teacher-student relationships and the establishment of supportive classroom norms (Pianta et al., 2012). These norms foster positive interactions and contribute to student engagement. Additionally, the impact of cooperative learning and group work on student achievement and social development has been highlighted (Cohen & Lotan, 2014). Classroom norms promoting collaboration and mutual respect enhance learning outcomes. Moreover, studies explore the influence of effective teaching styles and specific classroom norms on students' social and academic adjustment (Wentzel, 2002).

Building upon these findings, studies presented in this thesis (Studies 1 and 3) further emphasise the role of classroom norms in creating interactive and engaging learning environments. These norms promote active participation and meaningful interactions among students. The use of digital tools alongside these norms enhances the learning experience. It is important to consider both the digital tools employed and the establishment of supportive classroom norms to create an environment that encourages collaboration, critical thinking, and constructive dialogue. By carefully integrating appropriate digital tools and implementing norms that promote active participation and collaboration, students can engage with the material and one another, leading to enhanced learning outcomes. Further investigation is needed to explore the impact of different game-play approaches and the interplay between classroom norms and digital tools on student interactions and learning outcomes.

The National Educational Policy (NEP) 2020 (Ministry of Human Resource Development, 2020) and Next Generation Science Standards (NGSS) (Council, 2013, 2015) emphasize the importance of interactive classrooms that prioritize student-centered learning, the use of digital tools that facilitate collaboration, and the implementation of self- and peer-assessment. This thesis presents studies that demonstrate what such a classroom looks like. The studies also highlight the significance of considering both the student-centered approach and the design of digital tools and classroom norms. Study 3, for instance, reveals that while both the CSS and CSG settings employed student-centered pedagogy, the CSG setting witnessed increased social interactions, peer-assessment, and a change in the teacher's role. This difference in outcomes can be attributed to variations in the design of the digital tool and the norms followed in the classroom. Which indicates that these factors play a role in shaping the observed differences.

6.6.4 Shared Memory Space affected the Pattern of Interaction in the Classroom

The influence of shared memory space, gameplay, and classroom norms on the patterns and context of interactions within the classroom setting is another aspect I studied in this thesis. The findings shed light on how these factors shape the dynamics of student interactions and the overall learning environment.

In Study 3, the comparison of the two settings revealed important insights. In the CSS setting, the pattern of interaction closely resembled that of a traditional classroom (Sarangapani, 2003b). Students primarily interacted with the teacher, adhering to the established power dynamics. However, in the CSG setting, where a shared memory space was introduced, a notable shift in interaction patterns was observed. Within the CSG setting, students not only engaged in discussions with their peers but also actively interacted with the teacher. This change in interaction dynamics created an environment where students felt empowered to argue and challenge ideas. The power dynamics in the CSG setting were less skewed compared to the CSS setting or a traditional classroom (Sarangapani, 2003b).

The introduction of shared memory space in the CSG setting enabled students to engage in competitive gameplay, fostering a context where their interactions became more dynamic and multifaceted. The shared memory space provided a medium for students to exchange ideas, challenge perspectives, and collectively construct knowledge (Müller et al., 2017; Roschelle & Teasley, 1994). These findings underscore the importance of shared memory space, gameplay, and classroom norms in influencing how interactions occur and the context in which they take place. Including these elements in the learning environment promotes a more inclusive and participatory atmosphere. By encouraging interactions between peers and facilitating engagement with both peers and teachers, the classroom becomes a space that fosters active involvement, critical thinking, and a sense of responsibility for the learning process. National Educational Policy (NEP) 2020 (Ministry of Human Resource Development, 2020) aligns with these principles by emphasizing the importance of fostering critical thinking, student ownership of learning, social interactions, and active engagement in the classroom.

The introduction of shared memory space, coupled with gameplay and supportive classroom norms, has a profound impact on the pattern and context of interactions within the learning environment. Creating a collaborative shared space empowers students to engage in meaningful discussions, challenge ideas, and interact with both peers and the teacher. This approach cultivates a more inclusive and dynamic learning environment, enhancing student engagement and promoting deeper learning experiences.

6.6.5 The Advantages of Shared Memory Space for Offloading and Peer Interactions

One notable advantage of shared memory space is that it enables students to offload their representations onto the screen (Hutchins, 1995; Kirsh, 2010). This cognitive offloading allows learners to allocate their limited mental capacity to more critical activities such as complex mental calculations or decision-making processes (Hutchins, 1995; Kirsh, 2010).

The act of offloading and immediate sharing in the shared memory space opens up new possibilities for peer learning and assessment. Students can readily access and examine their peers' representations displayed on the shared screen. This not only promotes collaboration but also provides a scaffold for learners. Students can refer to their peers' representations to gain hints or verify their own calculations, fostering a supportive and interactive learning environment (Roschelle & Teasley, 1995).

Moreover, the relatively permanent nature of representations on the shared screen offers additional advantages. The persistent presence of representations allows for re-checking and revisiting previous work, enabling learners, their peers, or the teacher to refer back to these representations whenever needed. This feature facilitates peer assessment, where students can evaluate each other's work based on the shared representations. It also allows for ongoing feedback and guidance from the teacher, who can refer to the shared representations to provide targeted support (Golbeck & DeLisi, 1999).

The shared memory space not only enhances collaboration and peer interactions but can also promote a deeper understanding of concepts and strategies as shown by the students in the CSG setting during FGD. By having access to a collective set of representations, students can engage in critical analysis, compare different approaches, and identify common patterns or errors. This shared sense of knowledge construction contributes to a richer learning experience and fosters a sense of ownership and responsibility among students (Roschelle et al., 2002; Roschelle & Pea, 2002).

The utilization of shared memory space provides significant advantages for offloading representations and fostering peer interactions in educational settings. It liberates students' cognitive resources, enabling them to focus on important activities and decision-making processes (Hutchins, 1995; Kirsh, 2010). Additionally, the immediate sharing and relatively permanent nature of representations on the shared screen facilitate peer learning, peer assessment, and ongoing support from the teacher (Roschelle & Teasley, 1995). By harnessing the benefits of shared memory space, educators can create collaborative and engaging learning environments that empower students to maximize their cognitive potential and deepen their understanding of the subject matter (Roschelle & Pea, 2002).

6.7 Implications[25]

6.7.1 Implications for Instruction Using Digital Games For Mathematics Learning

The study produced a digital game that can be used to help children learn arithmetic. Similar games can be designed using the instant messaging environment to help children learn other topics such as multiplication, division, and fractions.

The games with shared memory space (SMS) in mathematics learning are beneficial, particularly in addressing mathophobia, a term coined by (Papert, 1980) to describe the fear and anxiety associated with mathematics. These games create a virtual mathland where students engage in mathematical conversations and terms, fostering a natural learning environment. Through public constructions, such as the chat feature in our case, learners can actively build their mathematical knowledge (Papert, 1980, 1993).

The incorporation of SMS in digital games not only makes learning joyful but also provides cognitive and emotional support through social interactions. By creating opportunities for peer interactions, these games enhance students' engagement in the task and promote peer learning, assessment, and the development of supportive relationships. In a math class, having friends who can help in taking on challenges rather than avoiding them becomes crucial (Takeuchi, 2016).

6.7.2 Implications for Design Of Instructional Games

This study also suggests that games with SMS are better at helping children learn than solo ones. A space that allows externalization and instant sharing of representations among participants has certain advantages. Therefore, designers of instructional games should include features that allow the externalization of representation. It can help lower the learners' cognitive load, and instant sharing of those representations can make them accessible to other learners.

[25]This section is published in: Shaikh, 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.

This study echoes the suggestions by other researchers (Barab et al., 2005; Bransford et al., 1990; Kiili, 2005; Kirriemuir & McFarlane, 2004; Klein & Freitag, 1991b; Papastergiou, 2009) that instructional games should be as simple as possible, especially when designed for young students. Games should not consume considerable time in learning the rules [Papert (1980) calls it 'low threshold']. 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.

6.7.3 Implications for Learning Scientists And Education Researchers

Any tool that facilitates, mediates, or supports social interactions is beneficial for learning. Creating space and opportunities for social interactions inside the classroom can help students learn through cognitive and emotional support. Affective dimensions of peer interactions should not be ignored. Few peer interactions can invoke anxiety, whereas others can build confidence and positive status. Therefore all social interactions should not be considered the same, and attention should be paid to what type of emotions any instructional material that involves social interactions invoke. Similarly, educators should remember that the affective aspects also impact social interactions and learning.

Finally, having a shared memory space in the classroom can open an extra channel for students' interactions. Verbal interactions have limitations; many students can not speak simultaneously, and verbal utterances vanish immediately and can not be accessed later.

Studies presented in this thesis and studies by Stahl and colleagues (2008) 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. Not all students can create representations simultaneously, and there is a limit to how many representations can be created without rubbing previous ones. Digital shared memory space solves this problem, provides simultaneous access and provides almost limitless space for creating representations wherever students want.

6.8 Limitations of the study

The studies conducted in this thesis project had certain limitations that should be acknowledged. These limitations are discussed below:

- In Study 1, the students "owned" laptops, which they used both at school and at home. However, in Study 3, due to various issues, the students only interacted with the laptops during ChatStudio sessions on alternate days. It is worth noting that the findings would have been even more robust if the students in Study 3 also had "owned" laptops. Additionally, the focus on arithmetic, a subject with well-established rules, in the game design could raise questions about the generalizability of this approach to other subjects/topics that do not have such well-established rules.

- Study 1 had two major limitations. Firstly, the sample size was small, which restricts the generalizability of the findings. Secondly, I was unable to observe game sessions that took place outside of school, despite a significant number of such game sessions occurring. This limitation created a blind spot, as I missed the opportunity to observe groups that self-organized for play and learning. To address this limitation, future research could include a larger sample size and incorporate observations of sessions beyond the school environment to provide a more comprehensive understanding of the impact of the game.

- To measure students' engagement, I relied on data from computer logs. While this data provides valuable insights into the behavioral aspect of engagement, it does not capture the affective and social aspects of engagement. Future research could employ additional measures, such as surveys or interviews, to gain a more holistic understanding of students' engagement.

- In all of the studies, I assumed the role of a teacher. It raises curiosity about what would have transpired if the school teacher had facilitated the ChatStudio class while I observed it. This alternate approach could have provided a different perspective and enriched the study. Future studies could consider involving school teachers as facilitators to gain insights from their expertise and experiences.

- Another limitation to acknowledge is the use of computers as the primary technology platform. While the use of technology in learning games can have its advantages, it is important to consider the appropriateness of the technology and compare it to other types of learning games for mathematics, such as those found in platforms like gcompris. Future research could explore and compare different types of learning games to better understand their effectiveness in supporting student learning outcomes.

- Finally, a significant limitation lies in my growth as a researcher throughout the course of the studies, analysis, and thesis writing. Reflecting upon this journey, I realized that I have evolved as a researcher over the years. It has become apparent that I missed certain observations and failed to record them adequately during the study. With my present understanding of the research process, I am confident that I could conduct a more rigorous study and collect higher-quality data. This acknowledgment highlights the need for continuous growth and improvement in conducting research.

Future Work

The research conducted in this thesis utilized OLPC laptops, which have become outdated. However it is worth noting that the Sugar Learning Platform (SLP), the operating system on OLPC laptops, is now accessible as an Android/Mac application called Sugarizer[26], offering comparable functionalities (see Figure 36) Additionally, modern cellphones possess the capability to connect with one another through a local network, presenting further advancements to consider when designing future learning applications. In India, digital games have gained attention; for example, The Science and Engineering Research Board

[26]https://sugarizer.org/

(SERB[27]) in 2022 announced inviting proposals for development and research on digital educational games . Such opportunities can be utilised to advance the work presented in this thesis.

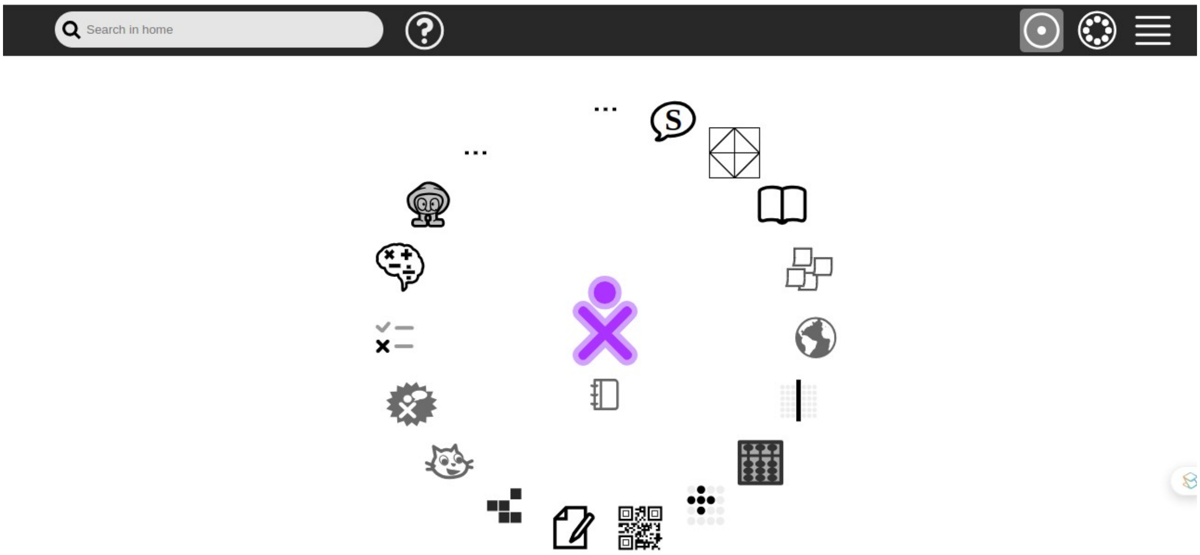

Figure 36: *Screenshot of Sugarizer platform running on Chrome browser. The Sugarizer platform is also available on Android phones as an app.*

Interactive flat panels (IFPs) have gained popularity in numerous Indian schools. As discussed in this thesis, blackboards can also be considered as shared memory spaces (SMS). However, IFPs surpass blackboards in terms of technological advancement and can also serve as SMS. It is worth noting that both blackboards and IFPs create a centralized classroom setup, where the teacher holds greater power and control. To gain deeper insights, future research can examine how IFPs, when utilized as SMS, shape the classroom environment in terms of interactions, attitudes, power dynamics, learning outcomes, collaboration, and other relevant aspects.

An intriguing discovery from this thesis pertains to the role of friendships within the classroom. Future investigations could delve into the process of constructing friendships, identifying factors that facilitate or hinder their development, examining the influence of

[27]https://www.indiascienceandtechnology.gov.in/announcementsopportunity/serb-announces-call-proposals-serb-inae-online-and-digital-gaming-research-initiative

technology on this process, and exploring how it contributes to the affective aspects of learning. By studying these aspects, we can gain a better understanding of the interplay between technology, social relationships, and the emotional dimensions of the learning experience.

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Annexures

Example of an analytic memo

Sr no	Computer log time	Participant	Post	Non-verbal	Verbal
1	17:25:19.520086	Teacher	17	Game starts	T: Write 10.. hmm sorry write 17.. write 17
2	17:25:21.072295	Aakash	17		T: Write 17
3	17:25:21.573305	Sadanand	17		
4	17:25:22.031942	Krishna	17		
5	17:25:22.458177	Sushma	17		
6	17:25:23.729547	Samita	17		
7	17:25:26.530124	Nikhil	17		T: Hey what happened? Start it again.. start it again
8	17:25:26.925064	Mayur	17		
9	17:25:27.165138	Amol	B-)१७		
10	17:25:27.819794	Mahesh	17		Nikhil: How many? T: 17 write 17
11	17:25:30.491995	Amol	१७		Mahesh: ok 17. T: Write 17

12	17:25:38.821203	Amol	17		Samita: adding number? T: wait... wait I'll say T: Did every wrote 17? T: yesssss T: Amol... hmm yes he wrote.. he wrote T: Amol.. hmmm ye he wrote T: Now... now.. add to it 7 T: start adding 7 to it S: 7? T: You have to go beyond 100
13	17:25:56.931586	Mayur	24	Samita starts calculating, she uses her fingers as a support while calculating	
14	17:25:57.177407	Amol	24		
15	17:25:57.970794	Sadanand	23	Sadanand made a mistake, posted 23 instead of 24	
16	17:25:58.315132	Nikhil	24		
17	17:26:00.243188	Samita	24	Samita finishes her calculation and posts 24. After posting she looks/stares at the screen	
18	17:26:00.704793	Krishna	24	Samita is still looking at the screen, she stands in	

				excitement	
19	17:26:01.419337	Amol	31		
20	17:26:01.897525	Mayur	31	Samita reports Sadanand 's mistake (posted 23 instead of 24) mentioned above.	Samita: Dada Sadanand made a mistake; he wrote 23 instead of 24. T: ok.
21	17:26:04.598399	Nikhil	31	Sadanand hears Samita's claim and holds his head.	Bharti : (inaudible, probably counting numbers aloud)
22	17:26:05.790866	Krishna	31	Sadanand stares at his screen, still holding his head.	
23	17:26:06.270818	Amol	38		
24	17:26:07.224829	Aakash	24		
25	17:26:08.762517	Sushma	14		
26	17:26:09.240590	Mayur	38		
27	17:26:10.447414	Nikhil	38		
28	17:26:10.940127	Mahesh	24		
29	17:26:11.625822	Sadanand	24	Sadanand corrects his mistake by posting 24 and starts calculating number for next step	
30	17:26:11.825775	Amol	45		

31	17:26:12.168497	Krishna	38	
32	17:26:13.568947	Samita	31	
33	17:26:14.063774	Mayur	45	
34	17:26:14.581125	Sushma	21	
35	17:26:16.953010	Nikhil	45	
36	17:26:17.142569	Amol	52	
37	17:26:17.340245	Aakash	31	
38	17:26:17.718668	Sadanand	30	
39	17:26:18.607730	Mayur	52	
40	17:26:19.480917	Samita	38	
41	17:26:19.954046	Nikhil	522	
42	17:26:20.504615	Krishna	45	
43	17:26:21.077578	Mahesh	31	
44	17:26:21.854650	Amol	59	Nikhil: Dada.. wrote 522 instead of 52 T: hmm who? Nikhil: Me T: hmm ok
45	17:26:22.754322	Sushma	35	

46	17:26:23.590967	Aakash	38	
47	17:26:24.263848	Mayur	49	
48	17:26:24.501681	Sadanand	37	
49	17:26:26.440134	Amol	66	
50	17:26:27.799037	Mahesh	38	T: start posting from 52 onwards
51	17:26:28.288223	Samita	45	
52	17:26:31.056689	Sushma	42	
53	17:26:31.534413	Krishna	52	
54	17:26:32.022635	Mayur	59	Bharti : Dada I got 51
55	17:26:32.517409	Sadanand	44	
56	17:26:33.170507	Amol	73	T: done? Bharti :hmm T: high five
57	17:26:34.462345	Samita	52	
58	17:26:34.948593	Nikhil	56	
59	17:26:36.079216	Mahesh	54	
60	17:26:37.035138	Mayur	64	

61	17:26:38.518833	Amol	80		Surjeet : look dada how is this coming
62	17:26:40.323892	Sadanand	50		
63	17:26:40.819389	Aakash	45		
64	17:26:41.339766	Krishna	69	Krishna makes a mistake, writes 69 instead of 59. But is he not visible in video as he has kept his laptop on his side instead of on desk and he is bent so desk covers him.	
65	17:26:42.483918	Samita	59		
66	17:26:42.985050	Amol	85		
67	17:26:43.620774	Mahesh	52		
68	17:26:44.185151	Nikhil	67		T: hey no hitting no hitting
69	17:26:46.048240	Krishna	66		
70	17:26:46.767448	Sushma	48		
71	17:26:47.490341	Samita	66		
72	17:26:48.443593	Amol	92		Bharti : dada he is pushing keys T: who is pushing
73	17:26:49.030723	Sadanand	57		

74	17:26:49.837754	Aakash	52		Archana: Dada I didn't
75	17:26:52.171973	Mahesh	59	Difficult to say what was Krishna doing when he realised his mistake. Through the gaps in the desk can see that just before pointing it to teacher he touches his head may be the sign that he realised his mistake.	Krishna: Dada there is a mistake, T: who did? Krishna: I did, I wrote 69 and then 66. T: ok go ahead complete the rest of the steps.
76	17:26:52.938597	Mayur	71	Krishna realises his mistake (wrote 69 instead of 59) and points it out to the teacher and class	
77	17:26:54.226733	Samita	73		
78	17:26:54.702200	Amol	99		Krishna: Dada there is a mistake, T: who did? Krishna: I did, I wrote 69 and then 66. T: ok go ahead complete the rest of the steps.
79	17:26:57.922802	Sadanand	64		
80	17:26:58.566526	Mayur	78		Aakash: Dada its 52 (refering to last number)
81	17:26:59.447371	Sushma	55		
82	17:27:01.496568	Mahesh	62		T: you have to go beyond 50.. sorry beyond 100.. do

					it.. do it
83	17:27:02.871118	Samita	80		
84	17:27:03.365891	Amol	1006	Amol crosses the last number, as per his calculation it is 106 but he makes a typo and writes 1006	
85	17:27:04.586469	Mayur	85		T: go beyond 100
86	17:27:09.240337	Sadanand	71		
87	17:27:11.245175	Sushma	62		Amol: data 106 Samita: I said it (referering to the mistake Amol made) T: did he made mistake?
88	17:27:14.635533	Aakash	59		Geeta: Dada... dada
89	17:27:15.698314	Mayur	92		T: Hey Amol she says you made a mistake, did you?
90	17:27:17.122370	Sadanand	77		T: She says you wrote 1006 instead of 106
91	17:27:20.168309	Sushma	69		
92	17:27:20.359519	Samita	87		
93	17:27:21.097275	Mayur	99		
94	17:27:21.610379	Aakash	66		

95	17:27:24.705737	Krishna	73		Geeta: How to remove this square? T: Remove or create?
96	17:27:25.796271	Sadanand	83		Geeta + Surjeet : Remove T: hmmm click here
97	17:27:27.944054	Mayur	106	Chat log shows that Mayur has crossed the last number, for him it is 106. He stands up and jubilantly shouts,	Mayur P: Dada... 106... dada 106 Amol: yes 106
98	17:27:29.337260	Mahesh	70		
99	17:27:29.791515	Amol	106	Amol corrects his typo and posts 106.	
100	17:27:35.109098	Samita	94		Mayur P: Amol you wrote 1006
101	17:27:35.602344	Mahesh	77		Amol: I also wrote 106
102	17:27:36.620903	Sadanand	89		Mayur P: chal (a marathi word used disapprove)
103	17:27:37.927388	Krishna	80		
104	17:27:38.648281	Sushma	72		Nikhil: he wrote 106 T: hmm then click here.. here here Nikhil: wrote 106 Amol: Ask dada.. I correctly wrote 106.

105	17:27:47.062811	Samita	101	Amol: I wrote 106 ask dada
106	17:27:48.631996	Sadanand	96	
107	17:27:50.739026	Mahesh	84	T: Look for mistakes .. look for mistakes
108	17:27:50.983770	Sushma	79	Bharti : (Calling teacher) inaudible Amol: Dada Samita made a mistake, final number can't be101 Amol: You get 100.. then 101 102 103 104 105 and 106 seven times
109	17:28:00.555160	Sadanand	103	
110	17:28:01.941739	Aakash	72	Amol: But she wrote 101 Sadanand : 103 it is 103
111	17:28:06.107114	Sushma	86	Amol: it can't be 101 T: Hey if we start from 10 and keep adding 7 what will be the first three-digit number
112	17:28:11.848578	Mahesh	91	
113	17:28:15.493995	Sushma	93	
114	17:28:19.411777	Aakash	79	Amol: Tai it is 106, right?

				Bharti : Dada dada
115	17:28:23.385510	Sushma	100	
116	17:28:33.882093	Sushma	107	T: hmmm 7 T: 24 T: 31 T: 38 T: Go sit at your places Bharti : Sush wrote 81 T: ok ok T: 45
117	17:28:48.286681	Aakash	68	T: 52
118	17:28:54.024866	Mahesh	98	T: 59 T: 66 S (can't be seen, male voice): it is 101 it is 101 T: 73 T: 80 T: 87 S: 89 no no 99 T: 94
119	17:29:08.387423	Aakash	95	T: 101 101 is correct
120	17:29:13.808866	Mahesh	95	T: you are right Samita: Sushmawrote 107

121	17:29:36.769770	Mahesh	102	T: hmm yes Sushma wrote 107 Mayur P: Dada we are correct we did it by counting T: what number is correct? Mayur P: we got 106 Samita: Dada Sadanand made a mistake, he wrote 103 Bharti : that colourful thing... thank you thank you Samita: Dada dada Sadanand s 103 is wrong it should be 101 Nikhil: Dada he wrote 103 instead of 106 S: huuuuuuuuu S: Dada Mahesh wrote 102 instead of 101 S: Dada he wrote 81 S: Dada Amol's 106 is wrong and I pointed it out
122	17:30:15.056698	ऋतुजा	ऋतुजाleft the chat	S: Aakash wrote 102 instead of 106 S: he wrote
123	17:30:16.237568	Aakash	102	

124	17:30:16.292232	Nikhil	Nikhil left the chat	
125	17:30:16.347802	वैश्नवी	वैश्नवीleft the chat	
126	17:30:16.478400	वैश्नवी	वैश्नवीjoined the chat	
127				S: 106 instead of 101 sorry 107
128				T: Ok lets go did everyone done?
129				Ss: Yes
130				S: Dada dada inaudible
131				T: Only Samita did all did all correct
132				T: Yes correct S: And me me Nikhil
133				T: Samita, Amol S: Yessss
134				T: Krishna S: Yeyyy
135				T: Aakash

136 T: Mayur S: Shelar?

137 T: Mahesh S: Yess

138 T: Sahi

139 T: Sadanand S: (inaudible)

140 T: Akshada

141 S: Kasa kele?