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The Singapore experience: Synergy of national policy, classroom practice and design research

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Abstract In recent years there has been a proliferation of research findings on CSCL at the micro and macro levels, but few compelling examples of how CSCL research has impacted actual classroom practices at the meso-level have emerged. This paper critically examines the impact of adopting a systemic approach to innovative education reforms at the macro, meso, and micro levels in Singapore. It presents the case for adopting design research as a methodology for CSCL integration that meets the needs of schools, and discusses a specific CSCL innovation that holds the potential for sustaining transformation in classroom practices. Our driving question is: In what ways can the routine use of CSCL practices in the classroom be supported by exploring systemic factors in the school setting through design research? We will explore the synergistic conditions that led to meaningful impact (at the micro level), mediated by systemic approaches to working with teachers in the schools (at the meso level), guided by Singapore's strategic planning for scalability (at the macro level).

Keywords CSCL practices · CSCL impact · Sustainability and scaling · School-based CSCL · Design-based research

> Decades of funded study that have resulted in many exciting programs and advances have not resulted in pervasive, accepted, sustainable, large-scale improvements in actual classroom practice, in a critical mass of effective models for educational improvement, or in supportive interplay among researchers, schools, families, employers, and communities.
>
> (Sabelli and Dede 2001)

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Introduction

With the realization of the immense challenges of putting real transformations of educational paradigms into practice, this quote made almost a decade ago still seems pertinent. Research supported by individual grants to researchers has produced interesting ideas, and small-scale proofs of concept. However, when one thinks about transforming school systems, one sees that the practical tools are fragmentary and scattered. Putting together a coherent classroom program requires work that has not yet been done. This work includes: surveying what is available and adapting it to local conditions; setting up infrastructure, carrying out the missing research, adopting long-term approaches to training and supporting teachers; and effecting a cultural change of public expectations, understandings and attitudes. These require massive funding for resources such as coordinated research, infrastructure, administrative support, training, teacher time for mentoring, and textbook materials (G. Stahl, personal communication 2009). The growing concern about the disconnect between education research—in particular educational technology research and classroom practice (Lagemann 2000; National Research Council 2002)—is still a looming challenge.

To surmount the above challenges, policymakers, researchers and practitioners need to make coordinated efforts when implementing reforms to impact real practices. In Singapore, there exists a combination of strong, explicit top-down directives and bottom-up desire for transforming and improving the educational system. Educational reforms can be actualized through a coherent program that spans the spectrum of many critical dimensions: from exacting top-down policy imperatives to encouraging school ground-up efforts, from translating research to impacting practice, from implementing one classroom project to scaling for more successes, from mere usage to effecting cultural and epistemological shifts of the stakeholders, and from experimenting with technology to providing robust national or district technology infrastructures.

This paper will focus within the spectrum of educational innovations in Singapore with specific examples of CSCL practices in four Singapore schools. While the field of CSCL has matured as a distinctive field of research over the past two decades, much of the published research on CSCL focuses on micro-level interactions. There is little reported research on the examination of classroom implementation issues and impacts of CSCL, especially those that consider multiple dimensions of educational reform. Through elucidating an account of design research, this paper discusses the impact and challenges of implementing a specific CSCL innovation in school contexts. In so doing, we argue for design research as the methodological framework for designing and enacting school-based research which can impact school practices as well as for refining theoretical understandings on how beliefs about the premises of CSCL are shaped and changed in the course of research implementation.

To make our point about the complexity and interplay of multiple dimensions of education reforms more lucid, the research innovations in this paper are discussed from a systemic change perspective that includes the micro, meso, and macro levels of educational systems. This paper briefly reviews the policy imperatives governing Singapore's educational landscape as macro-level factors, and the contextualized classroom-based interactions as micro-level factors. By meso levels, we support the view put forth by Jones et al. (2006) where they define: "meso is an element of a relational perspective in which the levels are not abstract universal properties but descriptive of the relationships between separable elements of a social setting" (p. 37). In other words, meso-level forces are situated within the encompassing socio-cultural environment where learning takes place.

Meso-level agencies can be perceived as the "recontextualizers" or "constructors of pedagogic discourse who de-locate and re-locate discourse, moving it from its original site to a pedagogic site" (Jephcote and Davies 2004, p 549).

We argue that the socio-cultural factors of the school's learning ecology constitute the meso-level environment and researchers from university research centres can be interpreted as an example of meso-level actors who work in that environment to re-contextualise pedagogic discourse. This re-contextualisation process will be referred to as a "meso-level" mechanism. The seamless orchestration of efforts from all actors will contribute explanatory power to the sustainability of an intervention. Figure 1 shows our conceptualization of a systemic framework for enabling CSCL practices via the alignment of macro, meso and micro levels in the Singapore context. By analyzing this pedagogy-driven reform at the macro, meso and micro levels, it is contended that the alignment of systemic forces at work will provide a buttress for sustainability.

The policy imperatives in Singapore

Singapore's systemic reform initiatives for ICT integration

Policymakers worldwide have to perpetually grapple with the 'wicked problem' (Rittel and Webber 1973, p. 161) of understanding the affordances of emerging technologies in order to formulate meaningful directions for pedagogy-driven reforms. In Singapore, there is growing emphasis on student-centered learning in order to prepare citizens for 21st century skills, competencies and dispositions. These issues are especially important in many Asian

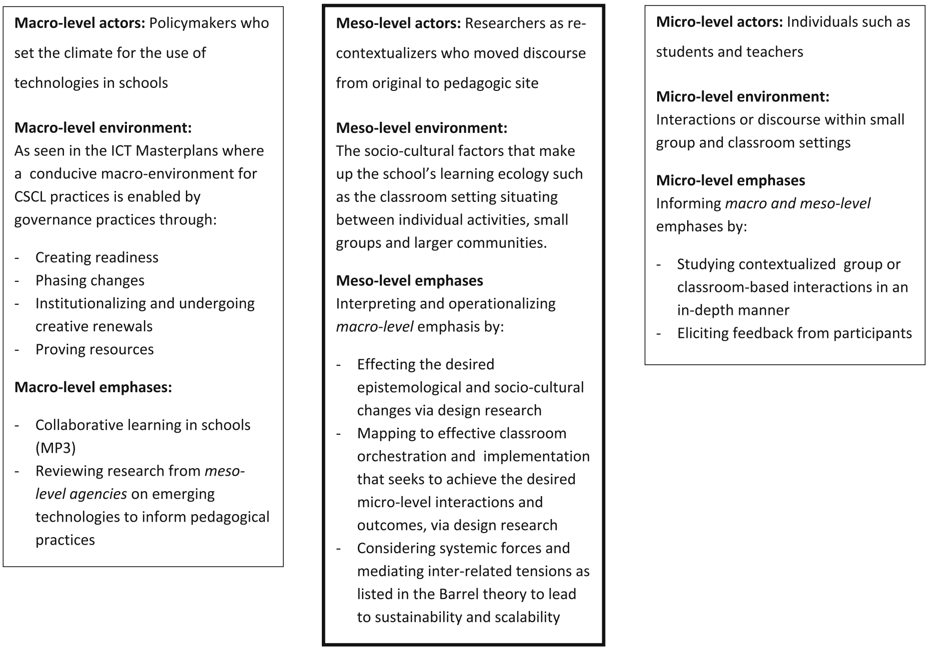


Fig. 1 A systemic framework for enabling CSCL practices via the alignment of macro, meso and micro levels in the Singapore context

school systems, which operate within a more centralized education system and a focus on standardized examinations compared to their Western counterparts. Well known for its academic rigor, Singapore students are constantly ranked by the Trends in International Mathematics and Science (TIMMS) as top performers in mathematics and science (TIMSS 2007). The challenge for Singapore now is to continue to excel in traditional assessments while preparing students for 21st century skills with learner-centered approaches. This shift calls for systemic changes to ensure that all components of information and communication technologies (ICT) policies are in line with the cornerstones of the nation's educational philosophy.

As analyzed from a macro perspective, the use of ICT in Singapore schools is pervasive due to the co-evolution of top-down and bottom-up approaches. The top-down approaches accelerated the adoption rate of technology in classrooms. With all stakeholders accepting accountability for implementing constant checks and balances, polices become dynamic in nature so as to reflect the changing needs of the global landscape in a timely fashion. In other words, the interaction among all levels of actors shapes and is shaped by the macro-level governance. Singapore's quest for infusing technology into schools started more than a decade ago, and the current knowledge is a culmination of critical and recursive reviews gathered from different phases of implementation.

The Ministry of Education (MOE) has worked with the schools since the inception of the first ICT Masterplan (MP1) in 1997. This Masterplan provided for the establishment of basic infrastructure and attainment of core competencies by teachers and students alike. A satisfactory outcome of MP1 was that teachers began to accept ICT as an integral tool and resource in their repertoire of teaching practices, which was not the case before MP1. Their willingness to tinker with technology for teaching is reflected in the results of the Second Information Technology in Education Study (SITES 2) conducted by the International Association for the Evaluation of Educational Achievement in 1999, in which Singapore school principals achieved an overwhelmingly positive attitudinal score of 90 on a scale of 100 (Koh and Lee 2008).

The second Masterplan (MP2) from 2003 to 2008, moved from a teacher-centric pedagogy to a learner-centric pedagogy, and allowed schools to have greater autonomy in utilizing their ICT funds to customize their ICT implementation (Koh and Lee 2008). The government recognized the differential pace of the implementation of ICT in the schools and therefore set realistic baseline ICT competencies, which all schools had to achieve whilst encouraging technology-ready schools to be trailblazers. This resulted in some schools forging ahead in adopting technology-enabled teaching and learning, while some schools still used ICT minimally as part of their repertoire of teaching practices.

Being cognizant of the goals, achievements and gaps of MP1 and MP2, the third IT Masterplan's (MP3, 2009–2014) focal point is to facilitate a greater level of technological integration in curriculum, assessment and pedagogy so as to equip students with critical competencies, such as self-directed learning and collaboration skills (Ministry of Education Singapore 2008). Thus, MP3 explicitly foregrounds a specific outcome for technology-enabled learning: to develop students to be collaborative learners. MP3 also recognizes the need to address the curriculum and assessment conundrum in order for technology-enabled pedagogical practices to really take off in schools.

It is the intention of MP3 to create a pervasive culture of innovative ICT practices across all schools and a corps of specialist teachers in every cluster of schools who demonstrate a deep understanding of how ICT can transform teaching and learning both within and outside the classroom. While it is recognized that the use of ICT needs to move in tandem with changes in curriculum, assessment and pedagogy, the challenge of reconsidering deeply ingrained institutional curriculum and assessment practices at the systemic policy level looms large.

Implications of systemic change perspectives

The preceding sections delineated Singapore's ICT-enabling journey from a macro perspective. One may ask, "What is the strength of Singapore's ecology?" and "What are the critical success factors?" These could be answered by closely examining how the three phases of the ICT Masterplans were planned and enacted from systemic change perspectives. Lessons reported in the literature have attested to looking at technology adoption and integration in the classroom and in schools as part of complex systems of change involving administrative procedures, curriculum, pedagogical practices, teacher knowledge, technical infrastructure and other logistical and social factors (Chang et al. 1998; Fisher et al. 1996; Fishman et al. 1998; Means 1994; Sandholtz et al. 1997).

In this section, we analyze the policy imperatives in Singapore by focusing on the four major phases of systemic-change processes for sustainability at the macro level. They are: 1) creation of readiness, 2) phasing of changes, 3) institutionalization and 4) ongoing evolution and creative renewal of the policies (Adelman and Taylor 2003, p 5).

Creating readiness

In order to establish a climate for transformation, the Singapore government works with meso-level actors such as researchers from the National Institute of Education to identify barriers of integrating ICT into education. Understanding the nature of barriers and identifying strategies to overcome them are important as they provide insights into how to create readiness and change mindsets for successful enculturation. As an example, researchers Lim and Khine (2006) identify barriers that four schools in Singapore faced for ICT integration and discuss strategies employed by schools to overcome such barriers. One of the barriers cited by the teachers in their study is the critical lack of time for preparing and delivering ICT-enhanced lessons as well as some technical problems. Other barriers include teachers' tendency to precipitate traditional modes of teacher-centered teaching. This is due to the coupling effect of time and resource constraints. Teachers also have reservations about sharing their successes and failures of planning and delivering ICT-integrated lessons.

In view of the complexity of the problem, the MOE has taken multi-pronged steps such as re-culturing and building capacity to tackle the challenges. For re-culturing, there are attempts to inculcate the value of student-centered learning during professional-development sessions as well as in-service teacher-training programs. Fostering local capacity building will help to enhance the sustainability of innovations. Local capacity-building strategies could include (a) supportive context such as incentives, professional development and information systems, (b) consultation and coaching, and (c) sufficient material and technical resources (Duttweiler 1995). To ensure that progress is not wrought by technical difficulties, schools are also allowed to hire in-house technical specialists to train teachers on ICT-related issues and to troubleshoot technical problems in the classrooms. MOE also espouses action research in schools to "social market" (Adelman and Taylor 2003, p21) data for appraising what is worth sustaining and how best to avoid costly mistakes.

Phasing changes

Adelman and Taylor (2003) argue that the diffusion of innovative projects is often crippled because "the nation's research agenda does not include major initiatives to delineate and test models for widespread replication of school-based innovations" (p21). In Singapore, this is addressed by the government's approach to phase changes and to elicit feedback from all stakeholders. For example, in the MP3 Implementation, fifteen schools are slated to be FutureSchools based on their technological and pedagogical readiness. However, the government selected the first five schools and studied them closely before calling for subsequent rounds of application for FutureSchool status. For the island-wide Standard Operating Environment (SOE) project where every school will be endowed with campus-wide wireless connectivity in 2012, the government—together with meso-level actors like system integrators—will implement the program in early 2011 in pilot schools before scaling up to other schools by the end of 2012. This circumspect approach allows for flexibility by policymakers to evaluate and fine-tune policies before jumping onto the bandwagon of innovation.

Institutionalization and creative renewal

With a proliferation of ICT related projects, there is a need for the institutionalization of sustainable development, where the concept will be embedded in government operations in the long term. The call for Singapore schools to conduct action research can be perceived as making such an attempt. Schools documented and critically evaluated their projects to make their tacit knowledge explicit. This serves to shorten the learning curves for other schools. In addition, the staggered approach of the three Masterplans is based on the iterative feedback from the previous attempts. The invaluable lessons learnt thus became an institutional memory. We can expect changes of the global landscape to be fast and furious, and it is an imperative for the local system to undergo renewals as well. This can be manifested in areas such as bringing in new stakeholders, revamping professional-development programs, upgrading infrastructures, reorganizing structures as well as creating wholesome environments for social and emotional support.

In sum, the policy imperatives, coupled with efficiency in their implementation at the ground level, serve as a key strength in Singapore's ecology, providing the commitment, funding, resources and vision to plan for reforms in schools to successfully harness ICT to enable students to learn better. A key strategy in MOE's policy imperative is to support funding for school-based research. To support the IT Masterplan in Education, Singapore's MOE established the Learning Sciences Lab (LSL) in 2005 to advance research on the efficacy of emerging technologies to improve teaching practices (Looi, Hung, Bopry & Koh, 2004).

Research supporting the policy imperative: The learning sciences lab

One characteristic of technology-enabled learning research in Asian countries is the close partnerships between researchers and practitioner communities like schools. In the praxis of research honed and informed by practice, the research community in Singapore has much to share on the design, development and evaluation of technology-enabled learning approaches and practices. Researchers in Singapore schools have capitalized on the nexus between research and practice. The Singapore Ministry of Education (MOE) funded the setting up of a Learning Sciences Lab (LSL) at the National Institute of Education (NIE) within Nanyang Technological University (NTU) in 2005 to do research to inform the planning and implementation of the MOE's Masterplan 2, and to conduct research that would help develop technology-enabled pedagogical models and practices. It was MOE's intention that new concepts and methods of ICT-infused pedagogy need to be prototyped, tested and transferred to classrooms and schools. LSL plays a role as the meso-level conduit that "provide(s) a means to re-interpret macro-level changes and to access the range of new choices that they present to subject factions and associations" (Jephcote and Davies 2004, p. 549). The LSL is positioned to strengthen MOE's capacity to undertake active research programs on the use of ICT in education as well as to expose school leaders and teachers to workable models and prototypes in order to transform their mindsets towards learning.

Realizing the enormous challenges of changing traditional pedagogical mindsets in schools, LSL has the long term view of deriving design principles that are scalable and sustainable. In the more immediate term, it aims to develop point-at-able examples through working with partner schools on practical school-based problems. By point-at-able examples, we mean demonstrable models of educational practice that policymakers, school leaders and teachers can look towards as models of what is desired. The models also point to possible outcomes arising from the research, and the implementation trajectories and challenges that might be faced when adopting these practices. The addressing of the school-based problems needs to be translated into research goals and questions. Within each of these questions, key learning theories are to be improved upon based on the research. If the research project is interventionist in orientation, design principles and factors or conditions needed for the innovation have to be documented and explained.

Remaining issues: How to impact CSCL practices in school

Meso-level issues

With background information about synergizing policy and research initiatives in Singapore, now we turn our focus specifically to the CSCL community. For the past two decades, CSCL has emerged as a distinctive field of research grounded on multiple theoretical perspectives of unpacking processes of collaborative meaning-making practices supported by computer technologies. In addressing the need to impact school practices, the CSCL research community has made a great advancement for theoretical understanding of the micro level of collaborative-learning aspects in small-group settings under specific local conditions. The idea of combining computer and collaboration to enhance learning experiences, however, is often viewed as a challenge in school contexts (Stahl et al. 2006). We argue that one of the core challenges in the CSCL community currently is how to influence practices beyond small-group cognition under highly contextualized conditions, and this issue necessarily requires more CSCL research looking closely into the complex interplay and enactment of multiple dimensions at the meso level of collaborative learning. By focusing on the interaction within small groups and larger cultural practices as separate entities, it is easy to miss the very mechanisms happening at the intermediate level, that is, the classroom setting situated between individual activities, small groups, and larger communities.

Here, the emphasis on meso-level interaction involves viewing a class and school as an ecological system with the potential to change. Within this view, classroom structure and culture for social interaction are no longer fixed, but can be designed and adapted with careful consideration of multiple dimensions such as cultural beliefs, practices, sociotechno-spatial relations, and interaction with the outside world (Bielaczyc 2006). Recently, Dillenbourg (2009) further substantiates this meso-level view by arguing the need for conducting more CSCL research on "design for orchestration," especially in terms of gaining a better understanding of the supporting and constraining conditions for the effective use of CSCL tools and practices. What underlies this notion of design for orchestration is the need to "empower teachers," and this starts from enabling deeper understanding of the fundamental challenges and issues that teachers are facing with CSCL ideas, tools, and practices. The effective adoption and enactment of CSCL approaches and tools in a classroom requires the teacher to be an "orchestrator." Teachers innovate in the classroom by orchestrating activities in an environment plagued by multiple constraints such as the need to attend to classroom management problems, adhere to curriculum requirements, consider appropriate assessment modes, work within tight schedules, design lessons that are compatible with students' learning spaces, and ensure that safety standards are met (Dillenbourg 2009).

Indeed, CSCL researchers who attempt to impact collaborative-learning practices in school often face cultural and epistemological challenges to transform classroom cultures. Dominant cultures in classrooms are still teacher-centric and individual-performance based, and collaborative-learning practices are not naturally cultivated with the mediation of CSCL technologies alone. This issue is even more prevalent and important in Asian countries than in Western countries, since much of the Asian school-assessment culture is based on individual performance, competitive assessment, and ability-based grouping.

A culture of social practices for collaborative meaning making has to be enculturated, and teachers play critical roles in orchestrating such endeavors during this enculturation process. Our interaction and conversation with Singapore teachers, however, shows that they tend to hold deep concerns and doubts about pedagogical approaches promoting greater student agency and social interaction, and about whether such pedagogical approaches would work for academically lower-achieving students.

Scaling up CSCL practices and empowering teachers

In Singapore, the term "collaborative learning" has appeared more frequently in the discourse of teachers, school leaders, and stakeholders due to the explicit emphasis listed on the government's reform agenda. Formal and informal structures are in place to support teachers to translate their pedagogical beliefs and knowledge of CSCL into actual practices. We have seen more cases of students participating and engaging in various CSCL activities in class and online. In sum, we believe that conditions for impacting schools with scalable CSCL practices are more conducive than ever.

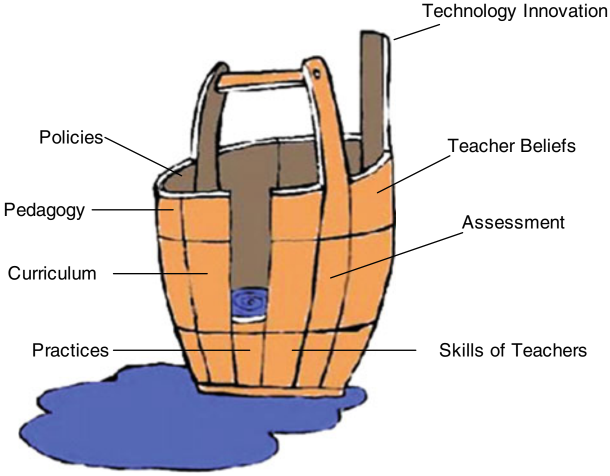
By impacting schools with scalable practices, we are talking about the complex interrelationship among teachers, school culture, leadership, and educational policies. Coburn (2003) defined scale as encompassing four interrelated dimensions: *depth, sustainability, spread*, and *shift in reform ownership*. Depth refers to deep and consequential change in classroom practice, altering teachers' beliefs, norms of social interaction, and pedagogical principles as enacted in the curriculum. Sustainability involves maintaining these consequential changes over substantial periods of time, while spread is based on the diffusion of the innovation to large numbers of classrooms and schools. Shift requires districts, schools, and teachers to assume ownership of the innovation, deepening, sustaining, and spreading its impact. Building on this work, Clarke and Dede (2009) added a fifth dimension, namely, evolution, in which the innovation, as revised by its adapters, is influential in reshaping the thinking of its designers and creating a community of practice that evolves the innovation.

Embracing the ideas of meso-level interaction and design for orchestration aforementioned, we revisit the issue of empowering teachers in terms of the two inter-related dimensions of scale by Coburn (2003), which are *depth of change* and *sustainability*. Lessons learned from prior technology-based educational improvement research clearly indicate the importance of empowering teachers and building capacity to effect deeper changes in teachers' beliefs, knowledge, and practices (Fishman 2005). Deep changes go beyond the superficial piecemeal changes in structures and procedures but work toward integrated changes in beliefs, norms of social interaction and pedagogical approaches enacted in teaching and learning practices (Coburn 2003). Teachers are more likely to embrace and practice CSCL when they can see the connection between the use of technology, the learning needs of their students, and the content of the mandated curriculum.

Another central element of scale is sustainability where changes are sequential and sustained *over time*. So far, we have seen some successful stories of CSCL research, but little is known about whether such successful practices have been sustained over time after an initial influx of resources and other forms of external support. We believe that more research documenting "implementation paths" (Bielaczyc 2006) and "essential tensions" (Barab et al. 2002) in the trajectory of adopting CSCL practices in classrooms are necessary. For sustained changes, we would reemphasize the importance of meso-level mechanisms that support teacher capacity building and reinforce school leadership and culture.

In re-conceptualizing scalable and sustainable CSCL practices, we argue that we need to take a design-based research approach in school-based work to address complex problems in real classroom contexts in collaboration with practitioners, and to integrate design principles with technological affordances to render plausible solutions. We use a Chinese proverb of the barrel metaphor (木桶原理) to represent why we need to adopt a comprehensive systemic perspective when a school adopts an innovation. The wooden-barrel theory states that the capacity of a barrel is determined not by the longest wooden bar or plank, but by the shortest (Fig. 2). As researchers, we tend to focus on just one or a couple of planks, but that creates a challenge for impacting practice. We extend the barrel theory to say that the capacity of a barrel is also determined by the seams or the lack of seams between planks, meaning that we need alignment of neighboring planks. Taking an intervention that is developed in the laboratory and supplanting it in school is least likely to work. Therefore, we need design research that entails working with stakeholders to help address their problems and

Fig. 2 The barrel theory



not just focus on the planks that are of research interest. We also need to adopt design research on a systemic scale to align the planks (for example, between curriculum, practices, and assessment as in Fig. 2), to look after the edges of the barrel, so to speak.

The goal of design research is to conduct rigorous and reflective inquiry to test and refine innovative learning environments as well as to refine new learning-design principles (Brown 1992; Collins 1992). Design-based research is iterative as researchers relentlessly strive to engage in design, work with teachers to enact the design in classroom settings, research on the contextualized learning processes, develop or refine theories of learning, engage in re-design, and continue the cycle of design and implementation. Design research is also characterized as being interventionist, iterative, process-oriented, utility-oriented and theory-oriented (van den Akker, Gravemeijer, McKenney & Nieveen 2006).

Example of school-based CSCL research from a design-research perspective

In this and the next few sections, we would like to describe an example of a LSL project that has the potential to be part of a sustainable transformation of classrooms into an environment that is conducive for collaborative learning. We will contextualise the design-based approach of the 3-year GroupScribbles (GS) project in Singapore and present its uniqueness in an Asian school context.

Interventionist strategies

The Singapore GS project is about bringing technology into classrooms to serve as a catalyst for introducing collaborative group work. As in most traditional classrooms reported in the literature (Mehan 1979; Nassaji and Wells 2000; Wells 1999), the typical discourse interaction in the Singapore classroom is the IRE (initiation-response-evaluation) pattern (Lossman and So 2010). In the IRE, a teacher initiation (I) is followed by a student reply (R), and then by the teacher's evaluation of this reply (E). IRE has been criticized for leading to unrewarding and boring classroom discussions. Most of the epistemic agency rests on the teacher: a student's primary, active, role is to respond. Changing such deep-seated traditional patterns of classroom discourse poses a considerable degree of challenge for educators. One of the objectives of the intervention is "empowering teachers" to be innovative in changing the traditional teacher-centered discourse patterns with CSCL ideas, tools and practices.

Context of intervention

In recent years, interactive technologies have been designed to support active classroom participation by harnessing the collective intelligence inherent in the classroom. One of the technologies is Group Scribbles (GS) 2.0 co-developed by SRI International and the National Institute of Education, Singapore. GS enables collaborative generation, collection and aggregation of ideas through a shared space based upon individual effort and social sharing of notes in graphical and textual form (SRI International 2006; please refer also to http://gs.lsl.nie.edu.sg). The GS interface consists of a multi-pane window. The default configuration consists of 2 panes: a lower pane and an upper pane, but the user can slide in more panes as desired. The lower pane is usually the private board, or the user's personal work area, with a virtual pad of fresh "Scribble Sheets" or notes on which the user can draw or type. The upper pane is usually a public board or group board, into which users can post their Scribble Sheets, position them relative to other Scribble Sheets and take items back to

Fig. 3 A Morae screenshot of the GS public and private boards

the private board for amendments or elaboration. When any Scribble Sheet is posted, moved or updated by a student, other students can see the effect almost immediately. On each pane, there is a drop-down menu to allow users to switch to other boards. Students post anonymously so as to freely express their ideas.

Group Scribbles is designed to be lightweight, flexible, customizable, and content independent so that activity design can be easily improvised by teachers for collaboration. It attempts to maximize the power of digital scribbling and interactive engagement, so that teachers can improvise different patterns of collaborative activities for students without the need for additional software programming (Chaudhury et al. 2006; Roschelle et al. 2007). GS enables students to get acquainted with an important 21st Century skill—Rapid Collaborative Knowledge Improvement (RCKI). RCKI seeks to harness the collective intelligence of groups to learn faster, envision new possibilities, and reveal latent knowledge. Its techniques include problem identification, brainstorming, prioritizing, concept mapping, and action planning (DiGiano et al. 2006; Looi et al. 2010b). Figure 3 shows a screenshot of the GS technology.

Creating readiness

We designed an intervention framework that articulates the RCKI principles for designing lessons (which will be discussed in next section) and activities that tap the affordances of GS. We postulated a logic model that links these principles and other contextual factors to the processes and outcomes of RCKI (Looi et al. 2010b). Our research explores the participation and discourse patterns in a GS class that seeks to harness collective intelligence. The enactment of RCKI principles in classroom discourse can support students in the GS class to generate more diverse ideas, and to build on and refine each others' ideas. In early cycles of the intervention as enacted in classroom implementation, we have focused on understanding the classroom and school culture, co-designing of the GS lesson activities, integrating the tool into holistic lesson plans, conducting teacher professional development, fixing technical problems that impede the smooth running of the technology, as well as informing the design of the new version of GS.

Our school-based research with GS interventions consisted of three stages which are implemented across different scales based on school conditions: 1) GS in two classes at one primary school (School M), 2) GS in two classes at two secondary schools (School F and W) respectively, 3) GS in a secondary School (School S) which uses ICT intensively and plans to have a whole-school GS adoption in a two-year time frame. Figure 4 shows the progress of our school-based research with GS interventions.

Within each stage of research in each of the schools, there was more than one cycle of GS implementation. Basically the intervention approaches are similar across the three stages. Next, we will describe the details of the primary-school intervention to illustrate our design-based research. The first stage of our intervention work involved a primary (elementary) school (School M). Participants included students and science teachers from two primary 4 classes, one of which is a high ability class led by a senior female teacher called Jeanette who had good pedagogical knowledge but limited ICT expertise, and the other a mixed ability class led by a young female teacher called Janet who had less experience in teaching but was confident in the use of ICT. Each class has 40 students. We followed this cohort of students for 2 years as they progressed from primary 4 to primary 6, by working with the teachers to design and enact science lessons using GS routinely. Figures 5, 6, 7 and 8 show the different configurations of collaboration patterns that were enabled by GS in these 2 classes. We will next describe the process of our design-based research.

Before the first cycle of the intervention work, the researchers observed the classes for a few sessions and interviewed the school leaders and teachers to understand the students

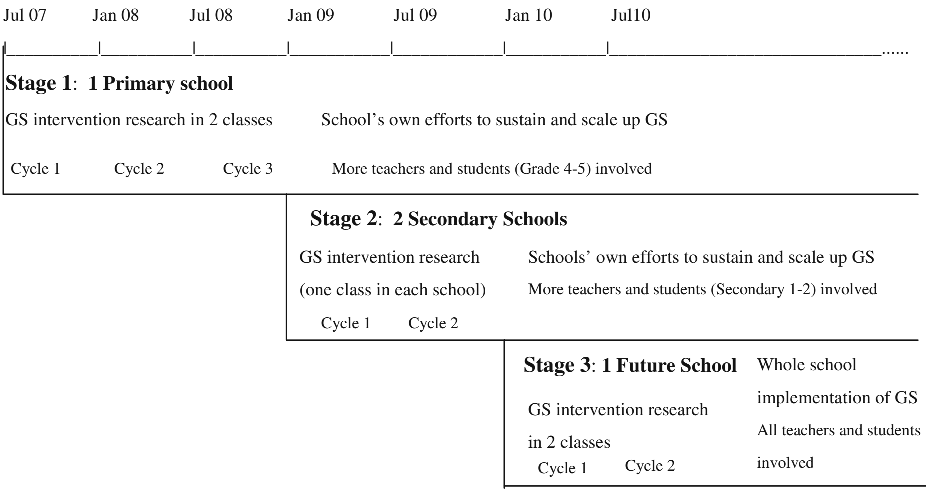


Fig. 4 Progress of school-based research

Fig. 5 Small group work using GS in the classroom

better. We found that the school leaders and teachers realized the importance of integrating ICT to support students' collaborative learning, but they lacked the pedagogical knowledge and technological skills to make it happen. The teachers believed that examination scores were the most important indicator of students' learning, and they hoped to see the students achieve higher examination scores after the integration of CSCL technologies in classroom learning. Some of the teachers had some misunderstanding of collaborative learning—they considered all group work as "collaborative learning" though some group work was not collaborative at all. In most of the classes we observed, there was a jarring lack of a collaborative learning culture. Sometimes students did group work by dividing the work and completing their individual part, and there was no interdependence among students. We found that the use of ICT in the classroom was still teacher-directed rather than student-centered. In most lessons, teachers used PowerPoint presentations to teach the students. The researchers decided to unpack the problems and to address them step by step. This marks the start of the first cycle of intervention. Figure 9 shows the process of our first cycle of intervention:

Fig. 6 Different collaboration patterns in the classroom: a student presenting to others in the group

Fig. 7 Different collaboration patterns in the classroom: a group of students presenting their group work to the whole class

Cycle 1

Before introducing GS to the class, the researchers and teachers had a few rounds of discussions to understand each other's needs and expectations. The researchers provided teachers with technical training on GS technologies and pedagogical training on RCKI theory and principles. The teachers shared with the researchers the context of the classroom culture, the students' background, their learning performance, and the schools' previous curriculum design and specific lesson objectives. With the realization that both teachers and students lacked the expertise to facilitate collaborative learning, the researchers and teachers co-designed 6 weeks (1.5 h each week) of collaborative learning activities by using Post-it Notes (we called it Paper Scribbles) to enculturate the teachers and the students to use rapid collaborative brain-storming and critiquing with the relevant protocols and social etiquettes. We felt that the classroom culture that engenders group collaboration, mutual engagement, problem solving and knowledge sharing should remain the same regardless of the technology used. In Paper Scribbles, easy-to-use sticky notes were adopted so that students could contribute their ideas and participate in the activities facilitated by the teacher. For example, they used a set of 3×5 inch Post-It® notes to guess animals based on characteristics given by each student, to post the names of organs in the human digestive

Fig. 8 Small group work with GS interleaved with actual science experimentation

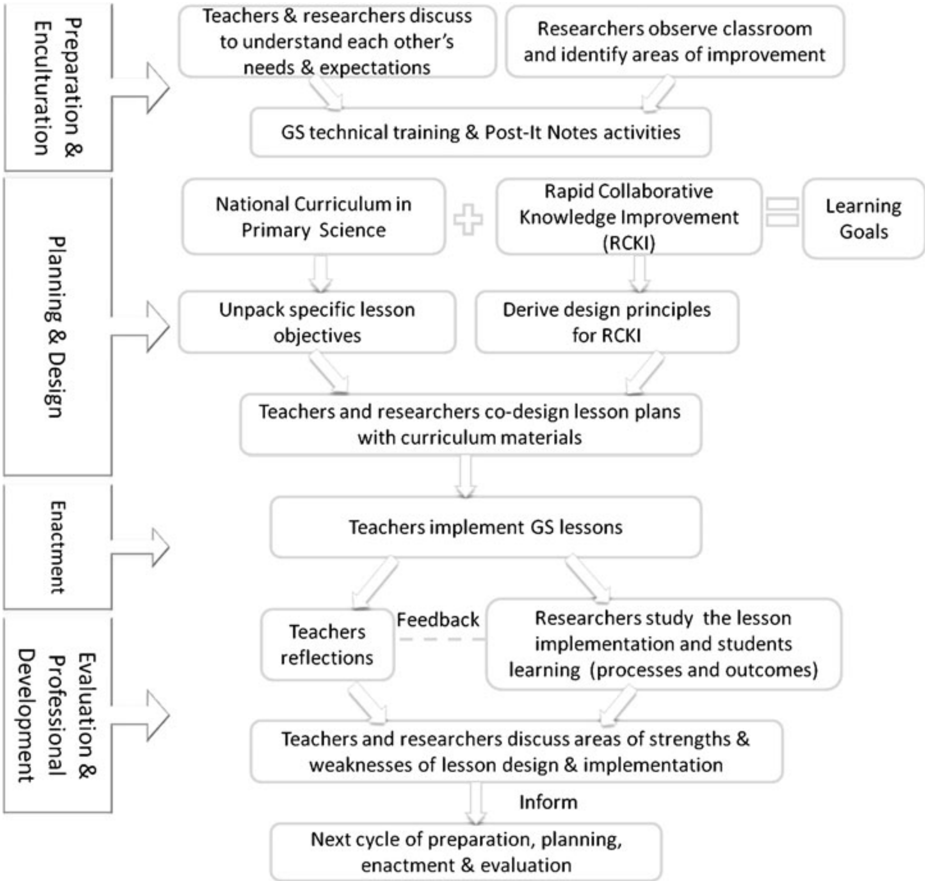


Fig. 9 Research Intervention Framework (One Cycle)

system, to post different living organisms in a particular habitat, and to classify fruits according to different characteristics. They used sticky notes to comment on each other's postings as well. Students worked in groups of four, in a face-to-face manner. They first posted sticky notes on A4 size magnetic boards ("group boards") and put them on the class whiteboard for other groups to see (Fig. 10). Sometimes the teachers projected the group boards onto a large screen for whole class viewing. At the end of the enculturation activities, the teachers and students were more conformable and confident with collaborative learning activities. Through this process, the students set the ground rules for themselves when doing collaborative learning activities, such as: "do not post for the sake of posting," "respect each other's ideas", "critique others' ideas in a polite way".

Subsequently, the classes were provided GS software and user training for two one-hour sessions followed by the routine use of GS technology for 10 weeks. Each week they had a one-hour GS science lesson in the computer laboratory and a one-hour traditional science lesson (non-GS) in the classroom. In the GS lessons, each student was equipped with a Tablet-PC (TPC) with GS client software installed. The GS lesson was implemented in learning situations where students used it to learn science topics in the standardized syllabus for the primary grade 4 curriculum - the circulatory system, energy, light, and heat. The GS activities were co-designed by the researchers and the teachers to achieve specific

Fig. 10 A enculturation activity in the classroom

objectives according to the curriculum syllabus. The lessons were designed not for the convenience of research, but were integrated tightly with the science-curriculum topics. Thus, the focus of Cycle one is enculturation of the students and teachers. To enhance accountability, the teachers and stakeholders co-designed the lessons, and students were given autonomy to set their own protocols for GS activities.

Cycle 2

Scaling up by achieving "spread"

After the first half-year of our intervention on science lessons (Cycle one), we sought greater depth of the innovation by continuing GS lessons for the science subject and expanding the subject areas to mathematics (taught by the same two science teachers) and Chinese language (CL, taught by two Chinese language teachers) and working with the same classes (Cycle two). By intensifying the usage of the GS technologies and the pedagogical practices enabled thereof, the students were given more time to develop into a community of collaborators well seeped in rapid knowledge-improvement practices across the curricula. At the end of the first year (two cycles) of school-based research with this primary school, we have developed a set of design principles for RCKI (e.g., distributed cognition, volunteerism, spontaneous participation, etc.) and curricular products for three subjects.

Cycle 3

Scaling up by achieving "depth"

By the end of the second cycle of GS intervention, the students were going to be Grade six students, who would be taking the national Primary School Leaving Examination (PSLE). The researcher felt that students had made great progress in RCKI—they were able to think actively, articulate ideas within groups better and critique other groups' work constructively. However, the class had yet to evolve into a mature community that did RCKI in a sustained manner. So after getting approval from the school leader, we implemented another cycle of GS intervention when the students were at Primary six. In this cycle, we took a more holistic view to design the GS lessons. Rather than designing a separate lesson based on individual lesson objectives and a particular collaborative pattern, we designed a series of GS lessons that allow students to engage in RCKI continuously with different collaborative patterns such as the jigsaw cooperative pattern. Thus our longitudinal work with this same class of students has allowed us to try variations in collaborative pattern design that should make the GS innovation adoptable and adaptable. At the end of the third cycle, the students had been doing more than 60 GS-based RCKI lessons and were able to form a knowledge-creation community that helped each other learn better collectively.

Scaling up by achieving sustainability, spread, and "shift" in ownership

After the end of the research cycle, the school (School M) started to sustain and scale up the GS work on its own accord by identifying key GS teachers to be the pioneers to conduct professional development for other teachers. It installed GS in one more computer laboratory so that more than one class can have GS lessons concurrently. The school adopted GS as the ICT tool in a 2-year school initiative code-named MAPLE (Mayflower Primary Literacy Excellence Program), which aimed to help students' literacy during their English lessons. In this way, GS was spread to five classes of Primary three students, with Jeanette appointed as the advisor for the use of GS as a tool in this project. For the Primary four and five levels, GS was adopted in one of the ICT modules in their science lessons (i.e., one module would use a few lessons using GS in their science curriculum for every class).

In terms of the shift in ownership, the school helped other schools adopt the GS innovation. The teachers shared their GS experiences with other school leaders of the same school zone. They demonstrated how they used GS for student collaborative learning in various educational events organized by MOE. Some teachers did action research on GS and shared the findings in different education conferences held in Singapore. This school also helped other schools that were interested in GS to set up the necessary GS infrastructure and to conduct teacher training. In January 2010, the research team and the school conducted a GS workshop for 30 teachers from more than 10 Singapore schools. The teachers shared their experiences and challenges of using GS for teaching and learning. Subsequently, six other schools decided to use GS for teaching and learning with the help of the Educational Technology Division of MOE.

Iteration of design principles

Ongoing evaluation and creative renewals

In our initial efforts to co-design instructional activities with the teachers, we sought to incorporate the following 10 principles of Rapid Collaborative-Knowledge Improvement (Looi et al. 2010a), of which the latter five were adapted from Scardamalia (2002):

(1) Distributed cognition—designing for thinking to be distributed across people, tools and artefacts,
(2) Volunteerism—letting learners choose what piece of the activity they want to participate in,
(3) Spontaneous participation—designing for quick, lightweight interaction driven by students themselves,
(4) Multimodal expression—accommodating different modes of expression for different students,

(5) Higher-order thinking—encouraging skills like analysis, synthesis, evaluation, sorting, and categorizing,
(6) Improvable ideas—providing a conducive environment where ideas can be critiqued and improved,
(7) Idea diversity—exploring ideas and related/contrasting ideas, encouraging different ideas,
(8) Epistemic agency—encouraging students to take responsibility for their own and one another's learning,
(9) Democratizing knowledge—everybody participates and is a legitimate contributor to knowledge,
(10) Symmetric knowledge advancement—expertise is distributed, and advanced via mutual exchanges.

Through the process of incorporating these principles into the real classroom lessons, we sought feedback and reflections from the practitioners and learnt the challenges that they faced in the classroom in enacting these principles. One challenge concerned the overlapping of concepts in some of the principles. Another was that the teachers had difficulty in understanding the real meaning and application of these principles. Therefore, we condensed these principles into six simpler guidelines, which teachers can more readily understand and enact:

(1) Make everybody think, as individuals and in teams.
(2) The class accepts new ideas, and constantly improves ideas.
(3) Explore many ideas, and from different angles.
(4) Students take initiative for their own learning.
(5) Everybody participates actively and contributes knowledge.
(6) Students organize their ideas and are self-reflective.

The researcher and teachers discussed these principles together and "prioritized" the principles based on students' experiences, skills and ability. For example, the teachers felt that principles such as "everybody participates actively and contributes knowledge" (principle 5) and "make everybody think" (principle 1) were easier to achieve, so we designed and implemented the subsequent GS lessons using these principles. Once students were able to think and participate class discussions actively, we designed and implemented GS activities that required students to organize ideas (principle 6), to explore and critique different ideas (principle 3) and to constantly improve ideas (principle 2), in this order. At the end of doing all these collaborative activities, students can take the initiative for their own learning (principle 4). With that, we were able to help teachers derive a better understanding of the gist of these guidelines. They were better enabled to design collaborative learning activities by drawing on the connections between these guidelines and the key affordances of GS.

Designing curricular products

Shared accountability with meso-level actors

Our curricular products consist of the lesson plans co-developed by the teachers and the research team. After the prior technical training and briefing on the use of GS, the teachers had a general idea of the affordances of GS. With some understanding of teachers' need to cover the syllabus content, we asked the teachers to draft the lesson plans with the lesson objectives they wanted to achieve, together with their ideas of using GS. The teachers drafted their lesson plans a week ahead of time, and shared them with the research team through email or a shared portal. Some teachers would share their teaching presentation slides and images/templates of the public GS boards (these templates were used as platforms to facilitate the students in collaborating with one another). After analyzing the lesson plans and their respective teaching resources from the perspective of the GS principles, the researchers provided feedback to the teachers on how to re-design the lesson plans.

Immediately after the GS lessons, post-lesson feedback sessions were held. Many teachers provided feedback that they found the support from the researchers in guiding them to reflect on effective ways of carrying out collaborative work using GS to be very valuable. Through these dialogue sessions held on a regular weekly basis, the teachers were able to adapt and be open about adopting a student-centred learning culture. The following key changes were observed in the curricular products when the teachers participated in their co-design and subsequent improvement:

(1) They were able to facilitate collaborative work with their designs of scaffolds (e.g., tables and mind maps) in the GS public boards.
(2) They were able to give guidelines for students to provide constructive peer comments to each other's work.
(3) They were more open and even able to design activities for inter-group interaction or collaboration such as patterns involving competition and jigsaw.

Professional development of the teachers

Capacity building

A key aspect of our design-based research work is the close working relationships we have had with the teachers of the participating schools. Weekly meetings were held before the lesson implementations to discuss the design of the lesson plans. Researchers would observe the enactment of the lesson in class. They would also provide technical support to facilitate the smooth running of the technology as well as to fix technical problems, if any. After the lessons, the teachers and researchers met to share reflections on the lesson, focusing on the efficacy of the lesson implementation.

We studied developmental trajectories of teachers as they integrated GS technology in their classroom lessons over the period of about one academic semester (half a year) for some teachers, and two or three academic semesters for other teachers. From the perspective of coherence diagrams for analyzing teachers' developmental trajectories in integrating GS technology (Chen et al. 2010), the coherence between a teacher's beliefs, goals and knowledge and the affordances of the technology is the main key in leveraging the technology successfully. Coherence diagrams capture the complex interplay of a teacher's knowledge (K), goals (G) and beliefs (B) in leveraging technology effectively in the classroom. The transition between each state of the coherence diagrams is nonlinear, implying the importance of ensuring high coherence right at the initiation stage. Support for the teacher, either from other teachers and/or researchers, remains an important factor in developing the teacher's competency to leverage the technology successfully. The stability of the KGB region further ensures smooth progress in the teacher's effective integration of technology in the classroom.

Achieving sustainability by ensuring coherence

The degree of coherence between the teacher's knowledge, goals and beliefs, and the affordances of the technology provides an indication of the teacher's developmental progression through the initiation, implementation and maturation phases of using technology in the classroom. Our analysis of three teachers' trajectories suggests that initial high coherence in a teacher's KGB region and having students who have already been enculturated with the technology-enabled pedagogies accelerate upward developmental trajectories in integrating technology in the classroom. Support from researchers, albeit an important factor, is secondary when compared with a teacher's KGB region.

Table 1 below summarizes the stages of our design research process and the outcomes of each stage that concerns design principles, curricular products, professional development and theory refinement.

Innovation is utility-oriented

Our narrative of the design research with the three schools demonstrates to some extent acceptance of the intervention by most of the teachers and by the schools. Phillips (2006) characterizes these main purposes of a piece of design research:

1. To contribute to an understanding of the design process itself
2. To throw light on some educationally relevant phenomenon associated with the intervention being designed
3. To actually design a technically impressive program, intervention, or artifact
4. Or to do two or all of these things.

The GS project prioritizes the third purpose, as at the outset, we want to design an innovation that can be sustained in the school as well as potentially scale-up to more schools. This purpose would meet our stakeholders' need, namely, MOE, the schools we worked with, and the teachers. As researchers working at the meso-level mediating between the ministry and the schools, while we foreground 3, we also identify contributions to 1 and 2. Indeed, this paper provides a contribution of a design-research process that has some impact on real world school practices.

As early as the first year of intervention, we started to collect encouraging results from our intervention. We did a comparison of the GS classes versus the non-GS classes by looking at the school's science summative assessments. The results show that the GS classes performed better than non-GS classes as measured by traditional assessments (Looi et al. 2010a). With GS, students were found to have more opportunities to participate in class discussions through both GS postings and verbal interactions, and were exposed to diverse ideas (Chen et al. 2010; Chen and Looi 2010). Analysis of data collected in the classroom as well as data on students' attitudes and perceptions indicate that GS facilitated students' collaborative learning, and improved students' epistemology and attitudes toward science learning (Looi et al. 2010a).

Critical reflections of the GS innovation

In summary, our GS intervention project has supported the routine use of CSCL in the classroom for 2 years in one primary school, and for a year in two secondary schools. Through our research, we have been able to explore systemic factors through design research, derive design principles for rapid collaborative learning, and build up some local

Table 1 Stages of design research on GS

	Design Principles	Curricular Products	Technology Development	Professional Development	Spread of Innovation
July–Oct 2007	Derived 10 RCKI principles;	GS lessons for P4 science	Limitations of GS 1.0 were encountered; these informed the design of GS 2.0	Two P4 science teachers were trained; their lessons were observed; post-lesson PD sessions were held	Two classes from school M used GS for one subject
	Organized class into groups of four and designed group boards accordingly to manage complexity				
Jan–May 2008	Use of 10 principles to design lessons;	GS lessons for P5 science, mathematics and Chinese language (CL); a wider repertoire of pedagogical patterns used	GS 2.0 (beta) deployed but several performance issues were encountered; these informed the next design of GS	The same teachers were supported to design and enact GS activities in mathematics. Additionally, 2 CL teachers were trained	Same classes and teachers from school M continued their use of GS for the three subjects
	Uptake analysis used as framework for community-based individual knowledge building (Looi and Chen 2010);				
	Better understanding of affordances of F2F vs online collaboration (Chen et al. 2010)				
July–Oct 2008	10 principles were too challenging for teachers to apply, so they were rationalized into six principles;	GS lessons for P5 science and CL	A more robust GS 2.0 version was deployed; The analysis of large amounts of classroom interaction data motivated the design of the analytical tool in GS	Continuous PD for the participating teachers	Same classes and teachers from school M continued their use of GS for two subjects

Table 1 (continued)

	Design Principles	Curricular Products	Technology Development	Professional Development	Spread of Innovation
	Logic models were developed to explain how each principle works (Looi et al. 2010b)				
Jan–Mar 2009	Designed principles for sustaining classroom community	More pedagogical patterns experimented such as the cooperative jigsaw pattern	GS 2.0 with activity management is deployed	School M identified key GS teachers to be the pioneers to conduct PD for other teachers; Researchers conducted PD for teachers in two secondary schools (W & F)	Same classes from school M continued the use of GS; School M helped other schools adopt the GS innovation; their teachers did action research on GS; GS research scale-up to two secondary schools (W & F) in three subjects
April–Oct 2009	Use of classroom data to study the RCKI principles helped sharpen understanding of the principles and conditions for their use	More diverse pedagogical patterns for secondary science, math and CL were designed	Wireless connectivity worked in one of the secondary schools; Analytical tool used to view interaction data; Technical challenges for schools to install GS 2.0; this motivates the design of GS Live and GS Mobile	Continued PD sessions for teachers	Same classes and teachers from three schools continued the use of GS; Primary school M scaled to more classes and continued their sharing and helped other schools; Secondary school F used GS for Chinese language learning and Math (two classes); Secondary school W used GS for Chinese language learning and Science (two classes).

Jan-Dec 2010	Explored GS collaborative patterns further for language learning, sharpening RCKI principles and conditions for language learning	More pedagogical patterns for language learning designed and deployed	GS in 1:1 Macbook with wireless network environment, refine GS2.0, analytic tool and activity management, developing GS live	Researchers and the teachers from three schools conducted two workshops for teachers from 20 schools in Singapore; Researchers conducted PD for English and Chinese language teachers in School S	Same classes from 3 schools continued; The 2 Secondary schools started their own scalability journey on GS: A team from MOE's Educational Technology Division worked with six other schools in Singapore on using GS for collaborative learning.

capacity in the teachers we worked with, achieving some re-culturing of mindsets. We practiced shared accountability with the stakeholders, namely the school leaders and the teachers we worked with, emphasizing their empowerment rather than just being a researcher-dominated innovation.

Towards the goal of doing CSCL research that impacts practices in school, we had argued for more research on the meso-level analysis. Our GS research is an example of this meso-level interaction. We view the class as an ecosystem and examine multiple interactions (social practices, culture transformation, accountability with various stakeholders, etc.) occurring at this level. Playing the role of meso-level actors, as researchers, we contextualized the application of RCKI principles to support collaborative learning in the schools we worked with. We moved the discourse of RCKI from research labs to pedagogic sites in the schools through a process of design research and thereby built up the capacity of teachers designing their own collaborative activities based on RCKI principles.

Taking a sociocultural perspective helped us to understand transformation at the meso level. It helps address our concern with how to design for collaborative learning at the institutional level by considering the meso-level interactions at the school level. It allows us to see the tensions:

- Between a teacher's individual capacity and desire to change and the imperative of school leaders for teachers to innovate,
- Between the researcher's desire to innovate and the teacher's desire to solve operational problems in the classroom,
- Between the macro-level perspectives of very broad policy directions and the challenges of operationalizing them at the school and ultimately at the teacher's level, and
- Between the micro-level perspectives of promising literature reports of interactions at the micro level and providing the institutional context for these interactions to take place.

As meso-level actors, researchers like us can play a role to mediate between these tensions and for the school to progressively adopt innovations through the iterative design research approach. The artifacts created by design research, namely, the curricular products, the professional development of the teachers, the teacher sharing workshops, the articulation of GS design principles, and the various presentations of GS to school practitioners provide a historical record and trail for the innovation to proliferate in the education community in Singapore.

In reflecting why this GS intervention works, we further postulated these supporting conditions for the success of GS intervention at the systemic level:

- We emphasized routine use in the classroom at the outset. In the first school that we collaborated with, we worked with the teachers for a period of 2 years, supporting them in the routine use of GS in weekly lessons. The routine practices help alleviate the novelty effect of experiencing a new technology and the associated pedagogy.
- The technology was simple and easy to use. However, we did not start with a technology focus at the outset. Instead, we provided enculturation opportunities for the teachers and students to enact collaborative practices first before using the technology (Fig. 10).
- We focused on face-to-face CSCL in the classroom. The technology was used in class to mediate student-student and student-teacher conversations, increasing the bandwidth of communication.

- We iterated and derived GS design principles that empowered the teachers to design collaborative activities. Our objectives were for the teachers to be ingrained with these sound design principles for designing pedagogy, so that even without the use of the GS technology, the teachers would incorporate such notions of rapid collaborative idea improvement in their teaching (Looi et al. 2010b).
- Our lessons tapped existing curriculum, and thus were integral to the learning of the curriculum. The RCKI principles fit well into the existing structure of the school curriculum. In the existing curriculum, each lesson has a topic to cover and specific learning objectives to achieve. Having RCKI activities that last for too long (e.g., more than one lesson) may affect the existing school class schedule.
- The lessons were co-designed by the teachers and researchers, providing ownership by the teachers of the lesson plans and resources. Towards the later part of the intervention, teachers were able to devise their own CSCL activities that tap RCKI principles using GS. At the end of the intervention, we arranged seminars for teachers to share their GS experiences and lesson plans with teachers at other schools.
- We provided extensive professional development for the teachers. We did socio-cultural design to help teachers orchestrate collaborative learning activities in the classroom (Dillenbourg & Jermann, 2010).

Our design research is interventionistic and iterative in nature while driven by rigorous theories, providing a methodological approach to better unpack the enactment, adaptation, and diffusion of practices under local conditions. Through design research, we were able to cater to the needs of building up the planks of the metaphorical barrel, and sealing the seams between the edges of planks nicely (Fig. 11).

The GS interventions were not always successful in every lesson. When doing school-based design research, we faced a lot of constraints and challenges. These are the short planks of the barrel.

- The researchers and the school are two different ecological systems. The two communities may not always see eye to eye with each other. The schools have a lot of different initiatives and many other priorities which are important for them. When there is a conflict between GS intervention and school's other initiatives in terms of teachers' time, lesson topic and other resources, GS may have to give way to the schools' other initiatives. One lesson we learned is that it is important to have deep understanding of the school's ethos and culture. The GS intervention does not stand alone, and it should be aligned with the school's strategic plans. Otherwise the intervention effort will not be sustainable and scalable.

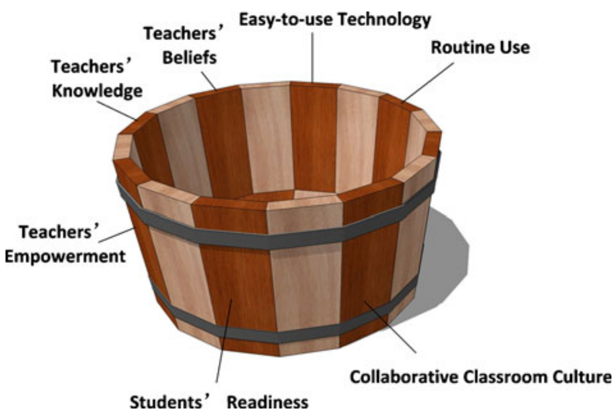


Fig. 11 How the Barrel for GS Innovation holds water

- Traditional assessment is always a concern for schools. It is not easy for researchers to establish causal relationships between the CSCL practices and traditional assessment. Many school teachers want to be assured that the intervention will help improve their students' examination scores before going to the next step for sustainability and scaling up.
- There is an inherent tension between efficiency and innovation for school teachers. Many teachers we have worked with are good at delivering lesson content and helping students obtain good scores in the examinations. However they may not be good at "thinking outside the box" and adopting/adapting innovations in classrooms. Part of the reason could be that the time allocated for each topic is somewhat fixed. Teachers believe that they have to cover all the content and get students to finish the worksheet within the allocated time. If they have extra time they will try innovation. If not, they prefer to stick to what they have been doing efficiently.
- Some of the school curriculum is not flexible enough for us to design meaningful collaborative learning activities. When identifying suitable topics for collaborative-learning activities with teachers, we found that much content is fact-based. They do not require students to use higher-order thinking and collaboration skills.
- Professional development of the teachers is very challenging for design-research in real classrooms. When introducing GS to classrooms, the teachers need to have a lot of adjustment to the new collaborative-learning pedagogy, the ICT environment, and students' new learning behaviours. Some teachers shared with us that they feel they need to be a "well-rounded" teacher to teach well in a GS class. The common issues they face when doing GS work are: technology breakdowns, classroom management of students when they collaborate with each other (e.g., off-task, negative comment, inefficient group work, free loader), monitoring 40 students posting GS scribbles at the same time, and consolidating students' ideas at the end of the lesson.

To create changes in school practices, we need to understand the different planks of the barrel, and to identify the shorter ones. All planks need to be long enough and to link seamlessly with each other to make the barrel work. In design research, we need dedicated and skillful researchers who understand and respect the school ecology, who can balance researchers' goals and schools' needs, and who can maintain good relationships with the teachers and provide sufficient professional-development support. In our journey with the schools, we realized that impacting practice is not easy, and the design research approach is more likely to be evolutionary than revolutionary.

Conclusion

We started by lamenting that the pace of education reform seems sluggish in the light of the cumulative amount of research grants that fund educational research that purports to transform teaching and learning. Many CSCL research projects report detailed findings at the interactional levels. Others present findings of experimental tests done in the lab. Still others look at CSCL practices at the macro level of communities, using a specific technology like wikis, World of Warcraft, or Knowledge Forum. When one starts to ask how these findings are relevant to actual classroom practice, there is inevitably a gap in the research literature on the strategies and proven ways of taking some of these findings and applying them within a real-world context. The work reported in this paper hopes to make an initial contribution to addressing the chasm between CSCL research and CSCL practices.

We approached this multi-faceted problem from the perspective of a meso-level view on orchestrating change in schools, including systemic change and the dimensions of scaling. We explored the conditions that favor the nurturing of innovations in a sustainable way using the barrel theory metaphor. We anchored our discussion through a description of how the GS technologies and the associated pedagogies were integrated into Singapore schools by virtue of the CSCL approach. The macro context of the school environment includes the IT Masterplans initiated by the government to support the use of technology in transforming teaching and learning in the schools. Our approach to working with schools is design research that allows us to work with the teachers to first co-design CSCL activities in classroom lessons and eventually to enable teachers to design their own CSCL activities. Methodologically, design research enables us to systemically research the enactment, adaptation, and diffusion of practices under local conditions, while being anchored with a set of design principles, namely, the RCKI principles. The focus of design-based research is to study learning environments not only for the advancement of theoretical understanding but also for the refinement of teaching and learning practices in practical contexts (Barab and Squire 2004). Hence, these RCKI principles are subsequently refined based on teachers' and researchers' in-depth understanding of the collaborative process at the micro level.

We started this journey in integrating CSCL into schools by working at the meso-level. Our GS research is integrated with a systemic effort that seeks to align the interests and goals of various stakeholders as well as the policies, the pedagogies, the assessment modes and the classroom practices. We describe the conditions that enable GS to have an impact—routine use, where the curriculum leverages the affordances of technologies, or where it is easy for teachers or students to add to the repertoire of technology-enabled activities.

There are many inter-relationships between research in CSCL and practices in CSCL. We have presented an example of a research innovation that has shown impact and exhibits potential for sustainability. While this case study is situated in the socio-cultural context of research and practice in Singapore, the principles of research and planning for sustainability are tenets that can be adopted for other countries and school districts as well.

Being able to determine the current state of affairs and the people's mindset towards alternative pedagogies and technologies is crucial. Understanding what CSCL research is and how it can be applied to improve the educational process in schools is the contribution we hope to make to the CSCL community. Our research experiences in the GS project led us to reflect on the nature of sustainable and scalable CSCL practices in relation to the multiple levels of the education system. In considering scale, it is easy to define it as a quantifiable measure, such as the number of students, teachers, and districts involved in research. As illustrated in the GS project, we wanted to highlight that scale involves expansion on both the vertical and horizontal dimensions, ultimately leading to deeper pedagogical changes in teaching and learning practices.

Although we foreground the meso-level interactions in this paper, we would also want to highlight that the success of school-based interventions is very often the result of systemic tinkering with all factors: macro, meso and micro. The micro-level interactions provide insights about group dynamics, which are also inter-meshed with meso-level forces such as the socio-cultural context of the school or class. Researchers who are meso-level actors strive to re-contextualize pedagogic discourse by studying micro-level factors and aligning school practices with macro-level policies. In the process of doing so, meso-level actors can potentially shape macro-level policies as well. By adopting the ecological perspective, we maintain the stand that the three different layers are inter-locked. They are all planks of the proverbial barrel. Since the binding constraints determine the outcome of intervention, all actors in the ecology should strive to remove the short-board effect. This can be achieved by maintaining on-going dialogues so that schools can ultimately benefit from the enduring and synergistic alignment of policy, practice and research.

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