Rapid Collaborative Knowledge Building: Lessons Learned from two Primary Science Classrooms

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Abstract: Cognizant that a critical 21st century skill is the capacity to do rapid collaborative knowledge building (RCKB) in a dynamic setting, we are interested to introduce practices for RCKB into classrooms. Through RCKB, students also have opportunities to learn and articulate their understanding in a deeper way than traditional classroom lessons. We describe a research project in which together with teachers, we initiated lesson activities that enact RCKB for science lessons. Towards that goal, we envisaged 10 principles for RCKB in the design of lessons, and worked with teachers to co-design lesson plans and apply these principles. Reporting on our initial pilot study, we document some effects of our intervention package in terms of traditional and non-traditional assessments of learning gains. We started with 6 weeks of initiation activities (a.k.a. "Paper Scribbles" or PS sessions) in the classroom using sticky paper notes, which was followed by another 10 weeks of activities in a school computer laboratory with the use of the Group Scribbles (GS) software technology. We share our lessons learned in this study, discuss implications for socio-technical instructional design of successful rapid knowledge building activities in the classroom, and suggest avenues for improvement and further research.

Keywords: collaborative knowledge building, distributed cognition, collaborative learning.

Introduction

Traditional patterns of classroom talk have evolved over a significant period of time, and are continuously reproduced as part of institutionalized schooling. Analysis of classroom discourse has been the subject of extensive educational research (e.g., Cazden, 1988; Edwards & Westgate, 1994; Mercer, 1995). The most typical or default pattern of classroom interaction is the IRE (initiation-response-evaluation) pattern which has been shown to account for a possible 70% of teacher-student classroom interactions (Nassaji & Wells, 2000; Wells, 1999). In the IRE, a teacher initiation (I) is followed by a student reply (R), followed by an evaluation of this reply (E) by the teacher. In this pattern, the teacher initiates discussion, usually with a question, students respond and the teacher provides feedback in the form of evaluation. IRE has been criticized for leading to unrewarding and boring classroom discussions. Changing such deep-seated traditional patterns of classroom discourse poses a considerable degree of challenge for classroom reform.

Moreover, there is an ever-increasing need to provide students with learning experiences that reflect the challenges and opportunities they will experience in the workforce of the 21st century. One key class of workforce skills relates to rapid collaborative knowledge building (RCKB). RCKB techniques include problem identification, brainstorming, prioritizing, concept mapping, and action planning (DiGiano, Tatar, & Kireyev, 2006). By harnessing these techniques in the classroom, it is possible for students both to learn existing subject matter more deeply and also to become participants in 21st century knowledge building practices. These techniques can be enacted with light-weight technology such as sticky paper notes (a.k.a. "stickies" or "Post-It" notes or "scribble sheets"), or with digital technologies such as Student Response Systems (SRS). A more sophisticated solution is Group Scribbles (GS), developed by SRI international, which 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. GS was built on a Tuple Space server interfaced with a client software written in Java.

We are interested in exploring the harnessing of RCKB in primary (elementary) school classrooms with the use of interactive technologies. Using a design research approach, we are interested to find out if RCKB can improve students' learning as measured by traditional and non-traditional assessments, and to innovate and test effective pedagogical practices enabled by both the paper and the electronic version of sticky notes.

Technology Support for RCKB

Sticky notes can be used effectively for individual or group conceptual work, such as brainstorming, prioritizing or visualization activities (Stacker, 1997). However, stickies have physical limitations such as the need for a lot of manual busy work (handing out, collecting, copying and duplicating, moving from place to place, etc.) as well as ongoing supply, archiving, and publication issues. It is also difficult for everyone in a large group to view a sticky note immediately, simultaneously, and remotely when someone publishes it. GS enhances the characteristics of sticky paper notes by providing their key features while avoiding some of their physical constraints. It has affordances of flexible support for brainstorming, deep dives, and collaborative decision making that is provided by stickies or scribble sheets, coupled with the automated distribution, collection, and aggregation support that is provided by Student Response Systems (SRI International, 2006). The GS user interface presents each user with a two-paned window. The lower pane is the user's personal work area, or "private board", with a virtual pad of fresh "scribble sheets" on which the user can draw or type (see Figure 1).

The essential feature of the GS client is the combination of the private board where students can work individually and group boards or public boards where students can post the work and position it relative to others', view others' work, and take items back to the private board for further elaboration. Figure 1 shows a lesson activity in class in which each pupil posts answers to the question "When does the heart beat faster /slower?" in the private board, and then moves their answers to the public board for sharing. The pupils' Scribble notes showed a multiplicity of ideas they generated which enabled the teacher to initiate discussions on the interesting postings. For example, one student posted "just before examination" in the category of "faster heartbeat", a contribution which surprised the teacher and the class, and which prompted the teacher to initiate a discussion on why this might be the case.

Thus GS supports collaborative learning, which is well-supported by the literature as an effective learning pedagogy (Koschman, Hall, & Miyake, 2002; Wasson, Ludvigsen, & Hoppe, 2003) in a dynamic class context. In collaborative classrooms, groups of learners and their teachers routinely work in more complex configurations than lecture-based classes. They take roles, contribute ideas, critique each other's work, and together solve aspects of larger problems, all to good effect (e.g., Hake, 1998; Palincsar & Herrenkohl, 1999). Managed flow of information and control is essential to the structure of many of these successful educational activities (Guribye, Andreassen, & Wasson, 2003).

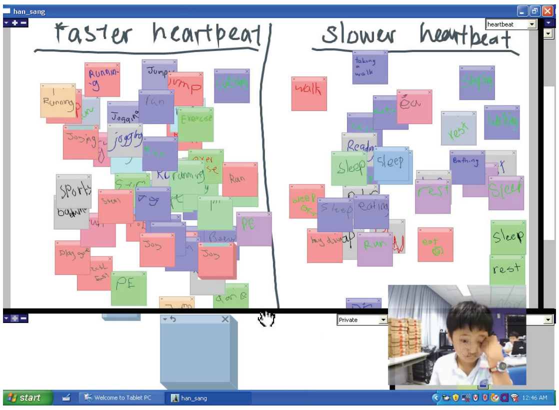

Figure 1. A Morae screenshot of the public and private boards.

Research Design

Methodology

For our research design, we adopted a design-research approach to school-based work on using GS as an attempt to address complex problems in real classroom contexts in collaboration with practitioners, and integrates known and hypothetical design principles with technological affordances to render plausible solutions. Our goal is to conduct rigorous and reflective inquiry to test and refine innovative learning environments as well as to define and refine new learning-design principles (Brown, 1992; Collins, 1992).

Intervention

In our work with a primary (elementary) school in Singapore, pupils and teachers from two primary 4 classes were provided software-usage training for 2 sessions of an hour each. Then they had 6 weeks of Paper Scribbles (PS) as an *initiation* phase, in which activities carried out in their school's Science Room. This phase was intentional as a means to begin *enculturating* the teachers and the students into the practice of 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 PS, easy-to-use sticky notes were adopted to facilitate the students' use in contributing ideas to activities posed by the teacher. For example, they used sticky notes to guess animals based on the characteristics given by each other, to post the name of the organs in the human digestive system, to post different living organisms in a particular habitat, and to classify fruits according to different characteristics, etc. They used sticky notes to comment on each others' posting as well. Students worked in groups of four face-to-face. They first posted sticky notes on an A4 size magnetic boards ("group boards") and then put them on the class whiteboard for other groups to see. Sometimes teachers put the group boards under the visualiser-projector system for public view.

Subsequently, the classes switched to the use of the GS technology for 10 weeks (see Table 1). Each week they had a one-hour GS Science lesson in the computer laboratory. Each pupil was fitted with a Tablet-PC (TPC) with a GS client software installed.

Table 1: Group Scribbles Activities.

Week	Topic of lesson	Activities
1	Circulatory System	1) Students post what the blood transports (e.g., water, air, oxygen/carbon dioxide, food, waste materials) 2) Students post answers to the question: When does the heart beat faster /slower? 3) Teacher group students' contributions according to activity/ emotions/others
2	Circulatory System	1) Individual postings of keywords learnt on blood vessels onto group board. 2) Group leaders eliminate the repeated postings.
3	Circulatory System of plant	1) Students compare 2 plants' system: One without water for a few days, the other has been placed in the dark for a few days, and post their contributions onto the group board. 2) Groups exchange boards to comment and improve on each other's postings.
4	Energy	1) Students list things that have energy or need energy to work in their group board. 2) They categorise the postings under the headings "Living things and Non-living things".
5	Light – Light resources	1) Students classify and post into their group board under the headings "Light Sources" and "Not A Light Source". 2) Groups exchange group boards to comment on/improve/get new ideas for own board. 4) Class to view and comment group boards in gallery-walk style
6	Light – House design	1) Students choose coloured and numbered tokens in GS. Students with the same number will belong to the same group. 2) Students decide on the different materials for the windows, doors and walls. 3) Groups discuss and comment on decisions if there are different opinions. 4) Groups did a gallery walk of the different boards. 6) Students vote for the best group on the public board. 7) Teacher comments on the boards.
7	Light-Shadow	1) Students are present with a diagram of a plant in a deep container with an opening at the top. 2) Group members brainstorm different ways to allow light to reach the plant and post their methods (by drawing or words) onto the group board. 3) Teacher shows a set of objects on the public board. Students in each group are asked to draw all the various possible shadows of these objects. 5) Students view each others' boards and comment. Students can perceive that objects cast different shadows depending on where the source of light is coming from.
8	Heat – Story of Crusoe	1) Students are posted with a problem situation – Robinson Crusoe is stranded in an island and needs heat to survive. 2) Students post all the different ways which Crusoe can use heat to survive. 3) Students explain the rationale of their postings. Teacher leads a discussion on conductors and insulators.
9	Heat - ways of slowing down the rate of melting	1) Students brainstorm ways of slowing down the rate of melting, using these materials: newspaper, paper towels, aluminum foil, plastic bag, ice cubes, rubber bands. 2) Teacher distributes the materials mentioned above to the students. Each group creates a container to prevent the ice cubes from melting, and leaves the container under the sun. 3) Group leaders come to the front and cut open the containers to pour contents into beakers. Those with the least water or the biggest ice cubes in the beaker would have designed the best container. Each group shares how they designed the container.
10	Heat - designs a cooling system to diffuse heat	1) 8 group boards named to A to H, will have the diagram of the computer and a water tank. Each group comprises of 4 members. Members 1 to 3 will each visit their respective numbered boards (1 to 3) to retrieve materials for the designing of a cooling system. 2) They could draw how they will use the material. Member 4 will be the coordinator to oversee the voting of the best group design. (Only 1 material from each board is allowed) 3) Groups visit each other groups' boards and comment if necessary. 4) Groups present their solutions to the whole class.

In PS as well as GS, the research team worked with the teachers to co-design and implement lessons. Throughout our instructional design, we tried to incorporate the following 10 principles of RCKB, 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 analysis, synthesis, evaluation, sorting, categorizing, etc.,
(6) *improvable ideas* – providing a conducive environment where ideas can be critiqued and made better,
(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) *democratized knowledge* – everybody participates and is a legitimate contributor to knowledge,
(10) *symmetric knowledge advancement* – expertise is distributed, and advanced via mutual exchanges.

After each lesson, we held sessions with each teacher to gather their feedback on the lesson and to give ourselves (teachers and researchers) a chance to reflect on what had happened in the classroom.

Research Questions

In this study, our research questions were as follows:

1. Does our intervention package (outlined above) improve pupils scores in science, as measured by traditional examination results?
2. What non-traditional learning gains (if any) are there using the aforementioned intervention package?

Data Collection

In our collection of data, at least 2 researchers observed each session and took down detailed field observation notes. One video camera was set behind the classroom to record the sessions. Screen capturing software Morae was used on 8 of the TPCs to record how each pupil interacted with GS on it. The video recordings were collected and transcribed. After the whole intervention, we conducted in-depth interviews with the 2 teachers and 8 selected students from each of the two classes.

Observed Effects

Traditional-Learning Gains

We are happy to report that our intervention using PS and GS was generally positive, both in terms of learning gains in the traditional sense, and in terms of some effects that are not measured in traditional assessments. Performance in traditional assessments is a concern not only of teachers, but of students, parents, principals and other stake-holders. We did a comparison on students' science exam scores at the end of the semester across all the 6 classes in the school, among which 2 classes (4F and 4C) are experimental classes with our intervention and the other 4 classes are control classes without our intervention (4A, 4B, 4D, and 4E). Among these 6 classes, 4F and 4E are high ability classes whereas 4A, 4B, 4C, and 4D have pupils of mixed-ability. Each class has 40 students. As the students' abilities across the six classes are not the same, we considered their science scores of previous semester as the covariate when comparing the science exam scores of the final semester. The result of Analysis of Covariance (ANCOVA) is shown in Table 2.

Table 2: Comparison of current semester Science exam scores across 6 classes, controlling for the Science scores of previous semester.

Source	Type III Sum of Squares	Mean Square	*F*	Partial Eta Squared
Corrected Model	61281.475(a)	10213.579	173.537**	.826
Intercept	19.256	19.256	.327	.001
PreScor	32648.971	32648.971	554.733**	.716
Class	983.481	196.696	3.342**	.071
Error	12948.164	58.855		
Total	942112.000			
Corrected Total	74229.639			

Note: ** $p < .01$.

We would normally expect higher-ability pupils to do better. Nevertheless, the results in Table 2 show that there was still a significant variation in science scores of the final semester among the 6 classes (F=3.342, p < .01) that cannot merely be explained by the previous semester's science scores (a proxy for the pupils' science abilities). Inter-class differences accounted only for 7% of the variance. The adjusted means of the current semester scores are shown in Table 3. It is shown that the 2 classes with our intervention (4F and 4C) have the highest adjusted science scores. The overall ANCOVA test being significant, a cursory glance at Table 3 shows that our experimental classes float to the top in terms of adjusted mean scores. Detailed pair-wise comparisons were conducted as a follow-up to compare the exam scores between each pair of classes (Table 4).

Table 3. Adjusted mean of the exam scores, controlling for the Science scores of previous semester.

	Class	Adjusted Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
GS classes	4F (High Ability)	65.973	1.376	63.261	68.684
	4C (Mixed Ability)	63.401	1.338	60.764	66.038
Non-GS classes	4E (High Ability)	61.180	1.290	58.638	63.723
	4A (Mixed Ability)	60.097	1.263	57.608	62.587
	4D (Mixed Ability)	60.010	1.311	57.427	62.593
	4B (Mixed Ability)	59.962	1.291	57.417	62.506

Table 4. Pair-wise comparison, controlling for the Science scores of previous semester.

		Adjusted Means Difference Estimate	F
4F	4A	5.875	9.124**
4F	4B	6.011	9.181**
4F	4C	2.571	1.568
4F	4D	5.962	8.886**
4F	4E	4.792	7.594**
4C	4A	3.304	3.395*
4C	4B	3.440	3.653*
4C	4D	3.391	3.505*
4C	4E	2.221	1.310
4E	4A	1.083	.342
4E	4B	-.219	.418
4E	4D	1.170	.379
4A	4D	.087	.002
4A	4B	.136	.006
4D	4B	.049	.001

Note: ** p < .01, * p < .1.

The pair-comparison results in table 4 show that GS "high-ability" class 4F had very significantly higher scores than the other 4 non-GS classes (p<.01), and higher (but not significantly) scores than 4C, the other GS class, which was of "mixed-ability". Class 4C had marginally significantly better adjusted-means compared to three non-GS classes 4A, 4B and 4D (p<.1) and even did better (but not significantly so) against the "high-ability" class 4E. There was no significant difference between any pair of non-GS classes. The ANCOVA results seem to suggest that GS had a significantly positive overall impact on the classes science examination results, whether they are of "high ability" or "mixed ability", at least in the samples that we worked with. Since 4C and 4F were taught by different teachers, the "teacher effect" may also explain why 4F's results so overwhelmingly trump the other classes'. However, we need further research to elucidate the exact characteristics of this "teacher effect".

Non-traditional Learning Gains

In addition to the above, we have evidence from interviews with teachers and surveys with students, corroborated with our own observations and field notes, of some positive changes in the class (including the teachers and students) toward cultivating 21st century learning skills and dispositions. We need to bear in mind that changes did not come easily, especially in teaching-and-learning cultures that are traditionally IRE, and even with deliberate design, there is always a natural tendency to revert to IRE modes. Teachers and students were also adjusting to the new software with its technical glitches, while adjusting towards a new classroom culture.

Improved Social Skills

Throughout the PS and GS activities, we found the emergence of etiquette that was socially co-constructed by students and teachers. In the first few sessions, students did not know how to comment on each other's work tactfully. Some students felt quite irritated when they saw scathing negative feedback from others. Even within a group, there were situations where students disagreed with one another and could not find a solution. The teachers and students discussed and jointly came up with rules that all should follow, for example:- *Be responsible for your own posting; Do not trash or hide other's posting; Do not create new boards without teacher's permission; Do not use SMS language in the posting; Do not repeat comments that have already existed; Posting should not be too lengthy in a scribble sheet; Only the group leader is allowed to use the big-Marker features.* Students then learnt to work more harmoniously and there was buy-in to those rules by the students. In some of the activities, students are encouraged to comment on other students' scribbles during sharing time. Many of their initial comments are just one word: "why?" The teacher initiated a discussion to show that this comment was not specific enough or useful to the contributor of the scribble being commented upon, and that comments should be more specific. In subsequent sessions, the comments were more targeted and specific.

Instant formative feedback

We observed instances of the GS activities supporting instant formative feedback from the students and from the teacher effectively. With the rapid formative feedback from the GS, the teacher can literally *see* students' misconceptions immediately and take corrective action. For example, in the first GS activity, when the students were asked to post "what does blood transport" to the public board, some students posted "blood" and "vessel". Such students seemed to manifest "associative" instead of "logico-deductive" reasoning. The teacher immediately pointed out the wrong answers and corrected them. Teacher L told us,

> "I particularly enjoy the instant feedback I get from my students' mass participation. I have many pairs of eyes to help me evaluate students' understanding. It saves on time as students help to edit postings during their visit to each other's board. They learn to reflect when comments are made on their postings. They learn through collaboration as they improve on each other's postings. This is indeed "more hands make light work". Students who are less inclined academically could learn from the instant feedback without feeling embarrassed."

Whole class participation

We observed high levels of attention and participation from the students in the activities. It is apparent to educators and even students themselves that some students do not speak up in class because they are shy. If these students try to speak but are not loud enough, their peers may ask them to speak louder, bringing further embarrassment. There are further reasons why some students do not speak up: (1) to preserve harmony and avoid confrontation; (2) having a perfectionistic streak, and (3) fear of embarrassment in front of the whole class. In the PS and GS activities, the whole class was engaged, which benefits all the students especially those passive learners and shy students. As shared by Teacher L,

> "Students who are vocal and articulate may tend to dominate the discussion but in GS, passive learners are given the opportunity to contribute as every member could participate at their own pace. Students are given plenty of opportunities to ask questions and to clarify their stand by posting and commenting. My weak students could learn from the postings of the higher ability students and the fast workers could guide the slow ones. With the introduction of GS, the learning experience enters a different phase. Students could discuss in groups without the need to drown each other's voice. They enjoy the freedom of expression without being ridiculed. The non-threatening atmosphere encourages the shy and reserve students to participate more actively. I could receive more contribution of ideas as compared to the conventional method of eliciting answers."

With GS and a culture of improvable ideas, students felt safe to make mistakes in small groups. Student B shared her view on the difference in classroom participation with and without GS.

> "he thinks that his answer may be wrong then he'll be like scared then he won't really answer; then if answer right means he's like about to argue with someone that means he disagree with something if he wants to raise up his hands and answer; if he's not sure or he knows that his

answer is like some point missing or something like that … He will not answer … with GS he really post and he really says his answer out."

Change in Epistemic Agency

We saw a gradual shift in the learning epistemologies enacted by the teacher and the students. Towards the last few lessons of GS, we could observe students engaging, explaining, challenging, and collaborating with one another. As the teachers got more and more used to the idea of distributed learning, they venture into more and more creative activities that disperse the locus of control to all members of classroom, taking advantage of the affordances of GS. Students took more ownership and responsibility for their learning. They enjoyed group work using GS. Says student B,

> "*Ya* they explain things (.) some things I don't understand (.) then they will tell me (.) oh actually this is this this this you know (.) like erm:: (.) we should put this in this way like the ice that experiment (.) they will say (.) er:; Manu he was sitting beside me (.) so I was like I think this is this and this and this this this (.) so its like (1) erm okay:: it makes a little bit of sense so I followed him "

This lies in stark contrast to the "traditional" way of learning, in which students learned science from the teacher (who may be boring) or from the textbook (which may be factually wrong) for the sake of gaining marks in the examinations. Some student who is "weak in science" and who struggles cluelessly to provide the "the one official correct long answer" expected by the science teacher, learning science can be rather daunting and demoralizing. Using designed lessons with GS, there was genuine sense-making, not learning for the contrived task of answering test questions. In the above interview excerpt, the interviewee was referring to the ice-cubes wrapping lesson, in which groups of students were given a set of 4 materials (a newspaper, a plastic bag, tissue paper, aluminum foil) and were tasked to discuss, via GS, the best order in which to wrap the ice cubes, and later implement their design.

In lesson 9 on designing a container to insulate heat loss, some groups who had the same theoretical design (order of wrapping of the insulating materials) obtained different results (different extent of ice melting). Students wondered why this was the case. The class then realized that it was possible that the ice-cubes could have been hand-handled with different amounts of time. With this hypothesis and out of curiosity, two of the students went home to experiment with the wrapping and they verified that holding the ice-cubes by hand longer does cause the ice to melt more, even with the same order of wrapping materials. This is something they would not normally bother to do when learning science, and this is beyond what they would have learnt from the textbook or a teacher in typical science lesson.

Better communication

Ostensibly, children and teachers use a common language (English, or the Singaporean version, Singlish) to communicate. However, there is a difference between children-to-children talk and teacher-to-children talk. A communication gap could arise between the teacher and students due, *inter alia*, to power-imbalances, a generation gap, different lingo used and time pressure on the teacher to complete the lesson. According to one pupil,

> "when we ask question, you know teacher right will frown like that [does frowning expression] teacher will do a frown. I think that I talk to my friends better than I talk teacher . my friend understand my language, but teacher say children language and my language is like different. …but when when I ask my friend right (.) teacher will just scolding why am I talking, then ok I cannot ask anymore."

In "traditional" classroom protocols, the teacher usually does most of the talking and students are supposed to be listening. Students will be afraid to ask one another to clarify points of the lesson. Sometimes, among peers, a significantly more precocious peer may talk in ways that bewilder others. Thus this could create a communication gap not unlike the teacher-children gap. GS facilitates the closing of this gap. Pupil K says:

> "When [student Y] talks it is very difficult to understand. So if he posted it, then [Teacher L] can at least … when [Teacher L] sees it she can explain …"

Thus we see GS not only opens up more channels of communication, but facilitates whole-class simultaneous communication at the children's level of understanding. The communication happens in parallel, and not in serial, and this affords the teacher more time to *care* for students' understanding (e.g. by polling through different group boards and giving quick comments as the students are working). In a traditional classroom setting, the teacher could only ask one or a few students at a time, and check their understanding. She would not be able to cater to everyone even if she wanted to. Some students may be raising their hands forever without having a chance for the teacher to clarify their doubts.

Shifts in Learner Identities

Before the Scribbles intervention, the identities students had in the class were those of unthinking copy-machines copying out the word-perfect, officially correct, "scientific" answers to their workbooks. Here is a testimony from pupil B:

> "*Ya* I'm learning better than in class (.) cos during the activity right (.) we're doing the workbook (.) teacher write on the board (.) oh copy copy copy copy copy (.) then after that we learn nothing …
> *Ya* cos teacher write on the board then we just copy down whatever she write on the board (.) cos sometimes we write wrongly right then teacher wants a answer to be (.) cos teacher seems like (.) teacher say that answer is correct (.) so must follow answer (.) so so we just copy down (.) we don't we don't use our brain at all."

In the course of the PS and GS lessons, there were indications that the students acquired identities in classroom as learners who contributed ideas. They also learn to hypothesize scientifically (what causes this, what if, etc) and think as young scientists. Using GS, there even arose a friendly competitive atmosphere to put in as many good ideas as possible, hoping to get the teachers' attention and praise.

Teachers also reported "spillover" effects after our intervention period. For example, they noted that some "weaker" students attempted to provide longer explanations in open-ended questions in written assessments. During peer marking of English compositions, students spontaneously sought for clarifications from their peer authors. In subsequent work, we plan to probe more deeply into these "spillover effects."

Surprises, Caveats, Areas for Improvement

In the course of our intervention, not everything went smoothly to our expectations. We share some of the lessons learnt and how we can address the issues in our future research.

Complexity of Instruction: We learnt that students may not be able to follow the teacher's instruction even in a class of better students, but especially when students are of lower linguistic or academic ability. In the GS lesson 10 on design a cooling system for the computer, a group of students came up with "handphone" which was not given in the list of cooling devices. In future, we will consider chunking and embedding of instructions in GS, and leaving "breadcrumbs" for students who got lost wandering off on their own to be able go come back on task.

"Creative" adaptations: There were examples of students' ways of using GS that were not designed for. Besides on-screen artistic doodling, we saw some groups "subverting" the democratic choice of tokens with a student grabbing all the tokens onto her private board, and only letting her friends take the tokens to form their own groups. It appears that students like to be in control in choosing their own group instead of forming a random group. Because the physical separation between some members and the lack of a chat tool, students resorted to hand signals, talking across the classroom and occasionally moving around in the classroom to where their teammates are seated. These show the emergent nature of real classroom dynamics powered by a piece of software such as GS.

Software and Technical Problems The most common complaint by teachers and students about GS was that it hanged or crashed frequently, disrupting workflow. GS was not originally designed for a large number of users and there are issues with bandwidth even in the case of wired connections. We tried wireless connection in the first GS lesson and it failed. There were instances where some students who "defaced" the public board or other groups' boards, accidentally or deliberately with the large Marker tool in GS, causing annoyance to the teacher and other students.

Conclusion

In this paper, we described how we adopted 10 RCKB learning-design principles, and how we initially enacted classroom activities with these principles, first using non-digital-technology support (PS) and later with technology support (GS) in two primary 4 science classes. Guided by a *proscriptive design* in a learning-conducive classroom *culture* of mutual respect and enacting classroom-interaction *protocols*, several *emergent* collaboration and coordination behaviours manifested by students in both non-digital-technology settings (PS) and technology-settings (GS) were observed. In particular, we saw better social skills enacted, more authentic communication, whole-class participation, shifts of identity, shifts in epistemic agency and better sense-making. For the pupil, GS afforded instant formative feedback from teacher and fellow students. Furthermore, in terms of traditional assessments, both the "stronger class" and the "weaker class" showed improvements compared to other classes that did not experience such an intervention. The results are heartening as these positive outcomes happened within half a year of our intervention. We feel that the initial lessons we co-designed with the teachers are only the beginning of even more powerful ways of tapping on different collaboration and coordination pattern activities. We shall continue to work closely with our partner school to refine the theory and practice of RCKB. Despite some teething problems and technical glitches, we are positive that GS, building on the lessons from the learning sciences and with the right technological and pedagogical designs that are sensitive to on-the-ground realities, will make a positive impact on students' learning.

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