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Multi-player epistemic games: Guiding the enactment of classroom knowledge-building communities

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Abstract Teachers and students face many challenges in shifting from traditional classroom cultures to enacting the *Knowledge Building Communities* model (KBC model) supported by the CSCL environment, *Knowledge Forum* (Bereiter, 2002; Bereiter & Scardamalia, 1993; Scardamalia, 2002; Scardamalia & Bereiter, 2006). Enacting the model involves socializing students into knowledge work, similar to disciplinary communities. A useful construct in the field of the Learning Sciences for understanding knowledge work is "epistemic games" (Collins & Ferguson, 1993; Morrison & Collins 1995; Perkins, 1997). We propose that a powerful means for supporting classroom enactments of the KBC model entails conceptualizing Knowledge Forum as a collective space for playing *multi-player epistemic games*. Participation in knowledge building communities is then scaffolded through learning the moves of such games. We have designed scaffolding tools that highlight particular knowledge-building moves for practice and reflection as a means of supporting students and teachers in coming to understand how to collectively work together toward the progressive improvement of ideas. In order to examine our design theories in practice, we present research on *Ideas First*, a design-based research program involving enactments of the KBC model in Singaporean primary science classrooms (Bielaczyc & Ow, 2007, 2010; Ow & Bielaczyc, 2007; 2008).

Keywords Knowledge building communities · Epistemic games · Design research · Implementation paths

The *Knowledge-Building Communities* model (KBC model) and its associated technology-based learning environment, *Knowledge Forum,* have been in the field of CSCL for over 20 years (Bereiter 2002; Bereiter and Scardamalia 1993; Scardamalia 2002; Scardamalia and Bereiter 2006). Although exemplars of the KBC model exist in various parts of the world[1], a better understanding is needed of how to bring the model to life in classrooms (Bielaczyc et al.

[1]Refer to http://www.ikit.org

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2013; Kolodner 2006; Chan 2011). As Scardamalia and Bereiter (2007) point out "getting teachers started is a crucial problem for FCL[2], Knowledge Building, and any other innovation that involves a major change in pedagogy… Among promoters of Knowledge Building there is considerable disagreement about the best strategy for getting teachers started" (p. 209).

One of the central challenges in enacting the KBC model is that it involves fostering a very different culture than those found in traditional classrooms, and even many reform classrooms. In KBC classrooms, the classroom community works to identify and advance the frontiers of their knowledge. The students assume "collective cognitive responsibility" and work to improve not only their own knowledge but also that of the entire community (Scardamalia 2002). Students work together on problems of understanding, create theories, carry out research and investigations in order to refine their theories over time, revise their problems and strategies, and share and monitor the progress of the community toward its goals. This stands in stark contrast to classrooms focused on coverage of bounded curriculum topics over short periods of time, answering questions with information provided by texts and the teacher, and individual work assignments.

Even in classrooms where extended inquiry and collaborative activities are common, there is a tendency to focus on investigations local to the individual or collaborative group, rather than working as a community toward "the collective solution of knowledge problems" (Scardamalia 2002, p. 70). Further, Scardamalia and Bereiter (1994) contrast the KBC model and other contemporary models of learning that seek fidelity between student work and the "real world" of work by pointing out that many of the other models cast students in the role of physicists, historians, and the like at the level of the individual. Instead, they propose:

> More significant implications follow if the question is reformulated at the level of the group rather than the individual. Can a classroom function as a knowledge building community similar to the knowledge building communities that make up the learned disciplines? (p. 270).

In order to function similar to disciplinary knowledge-building communities, students need to become "socialized into the world of work with knowledge" (Bereiter 2002, p. 220).

Thus, epistemic understanding and engagement in the practices of knowledge building involve individuals in acting as part of a collective endeavor. Students learn to use each other's diverse knowledge and skills as resources to collaboratively advance the community's understanding of a problem under investigation. The intent is to develop deep disciplinary understanding of both subject matter and ways of working with knowledge, and for members to come to respect and value differences within the community.

It should be noted that the necessary shifts in classroom culture are not expected to be immediate. However, introducing the KBC model is not viewed as a short-term intervention where a curriculum or computer-based environment is incorporated into the workings of the local settings for only a short period of time. Instead, enactment of the KBC model involves pursuing long-term change. Our interest is in understanding ways to support such a change.

Getting Started: Designing "Implementation Paths" for the KBC model

Although an extensive literature for the KBC model exists, only a small portion of the work has focused on initial efforts to create KBC classrooms (e.g., Caswell and Bielaczyc 2002;

[2] "FCL" refers to the *Fostering Communities of Learners* model developed by Ann Brown and Joseph Campione and their colleagues (Brown 1992; Brown and Campione 1994, 1996).

Hewitt 2002; Messina 2001; Scardamalia and Bereiter 1996). For example, in Caswell and Bielaczyc (2002), Bev Caswell, a teacher from the Institute of Child Studies in Toronto, shares her experiences in first working with Knowledge Forum to create a new culture of science learning in her 5th/6th grade classroom. However, these studies do not explicate strategies for "getting started" in becoming a knowledge building community. Our intent is to advance understanding in this area through investigating scaffolding tools that teachers can use to guide classroom enactments.

In our research, we take the challenges of fostering KBC classrooms in more traditional contexts as a starting point and engage in design research focused on the construction of *implementation paths* — the design of a trajectory that teachers and their students can traverse in order to navigate the desired shifts (Bielaczyc 2006, 2013; Bielaczyc and Collins 2006). The concept of implementation paths is based on the assumption that such change trajectories may be best supported by a set of differentiated design elements that help scaffold participants from their initial entry point toward a more robust enactment of the desired model. The goal of such design research is not to produce a step-by-step procedure of implementation, but instead to address the research question: how can we develop supportive tools and practices that socialize students into working together as a knowledge building community and deepen our understanding of critical change processes?

According to Scardamalia and Bereiter (2002):

> The basic premise of the knowledge building approach is that, although achievements may differ, the process of knowledge building is essentially the same across the trajectory running from early childhood to the most advanced levels of theorizing, invention, and design, and across the spectrum of knowledge creating organizations, within and beyond school. If learners are engaged in processes only suitable for school, then they are not engaged in knowledge building (p. 104).

That is, a KBC classroom should be seen as being on a trajectory, one where the knowledge work in schools is consistent with the knowledge work at advanced levels, such as disciplinary communities or knowledge-creating organizations. Thus, one way to conceive of constructing an implementation path is to support students in becoming aware of how particular communities work with knowledge, and to provide tools that scaffold student engagement in similar processes as part of their own classroom community.

Socializing students into the knowledge work of disciplinary communities can be conceptualized as learning to play the "epistemic games" of those communities (Collins and Ferguson 1993; Morrison and Collins 1995; Perkins 1997). *Epistemic games* are directed toward building knowledge and understanding (Perkins 1997). Like most games, they consist of rules, strategies, and different moves that guide play. Collins and his colleagues (Collins and Ferguson 1993; Morrison and Collins 1995) based their construction of epistemic games on studies of strategic play with disciplinary knowledge by Physical, Biological, and Social Scientists (e.g., the cost-benefit-analysis game, the systems-dynamics game).

Several design research projects in the Learning Sciences have found the construct of epistemic games to be useful in helping students come to understand the epistemic aspects of disciplinary work (see review by Sandoval et al. 2000). The power of the construct is in making knowledge work visible and permitting the forms, goals, and rules of the work to be explicitly discussed. Further, the game construct conveys that disciplinary knowledge work is not procedural nor routinized, but rather strategic and playful. The aim of engaging students in epistemic game play is to help them to develop *epistemic fluency*, "the ability to recognize and practice a culture's epistemic games, to understand their different forms of expression and evaluation, and to take the perspective of interlocutors who are operating within different epistemic forms” (Morrison and Collins 1995, p. 44).

One issue that arises in past work with the construct is that the types of epistemic games that researchers have focused on involve game play by individuals (e.g., Collins and Ferguson 1993; Morrison and Collins 1995; Sandoval, et al. 2000). Given teachers’ need to support students in coming to understand knowledge creation as a collective endeavor led us to extend the construct of epistemic games to “multi-player epistemic games” (Bielaczyc et al. 2013). Multi-player epistemic game play is intended to mirror the *distributed* efforts within disciplinary communities that result in the collective construction of knowledge. In multi-player epistemic games, the moves can be distributed across multiple players –- where individuals make contributions, others act upon such contributions (improve upon, synthesize, argue against, etc.), and knowledge is created and refuted through the collective workings of the whole. We elaborate more fully on this idea by grounding it in a specific example below.

Learning to play the “Progressive-Improvement game”

What kinds of epistemic games do members of a knowledge-building community need to learn to play? Scardamalia and Bereiter (2006) point to one central epistemic game in describing how “the direct pursuit of idea improvement brings schooling into much closer alignment with creative work as carried on at professional levels” (p. 100). We characterize this pursuit of idea improvement as the “Progressive-Improvement Game”[3] (Fig. 1).

In the Progressive-Improvement Game, players (wherever they be on the trajectory from K-12 students to professionals) work together on a common problem (*Our Problem*) by proposing *Initial Theories*. They may also generate *Questions* that identify areas in need of further investigation in order to refine their initial ideas. The players then work to gather further information through *Investigative Work* and/or the *Exchange of Ideas.* This, in turn, leads the community to theory refinement and further questions to pursue (*Improved Theories and Questions*). It is also critical to take stock of what the community has learned in order to understand the community’s current best understanding of the problem under investigation through periodic *Pull-Together*’s.

If we conceptualize the explanation-seeking inquiry of the KBC model as playing the Progressive-Improvement Game, then an important aspect of shifting classroom culture involves helping students to develop epistemic fluency in this game. The implementation path that we research in the present paper focuses on getting knowledge-building communities started in the classroom by supporting students in learning the rules, strategies, and moves of the Progressive-Improvement Game. Over time, students should then come to a better understanding of how these elements work together as part of a process contributing toward the progressive improvement of ideas.

How knowledge forum supports playing the progressive-improvement game

The KBC model is embodied in Knowledge Forum[4], a CSCL environment that allows learners to construct a communal multimedia knowledge base that visually traces the community

[3] In past publications we have referred to this epistemic game as the “Progressive-Investigation Game.” Here we change to a name that conveys more clearly the key goal of the game –- the progressive improvement of ideas.

[4] It should be noted that the *Knowledge-Building Communities model* and the name of its associated software, *Knowledge Forum*, have become quite synonymous in educational circles over the years. It is not uncommon for people to refer to classrooms that have adopted the model as “Knowledge Forum classrooms.”

Q22 **Fig. 1** The basic moves of the Progressive-Improvement Game

inquiry (Scardamalia and Bereiter 1991; 1994; Scardamalia 2004). Students share their work on common problems of understanding by entering their ideas and research findings into the Knowledge Forum database. Shared windows, or *Views*, provide a place for student's ideas to be made public to the rest of the community. Students can read through the knowledge base and make their own contributions. Student contributions can take many forms, including: (a) *Notes*, in which students state problems, advance initial theories, summarize what needs to be understood in order to progress on a problem or to improve their theories, provide a drawing or diagram, etc., (b) *Build-On's*, which are Notes that connect to ("build-on") previously-contributed Notes, and (c) *Rise Above's*, which are Notes that synthesize ("rise above") other Notes in the knowledge base. Students can also author their own Views, creating a new window to collect and organize various Notes from throughout the database in order to provide a particular perspective (a "view") on the knowledge work.

Figure 2 provides an example of a View drawn from a Knowledge Forum database where students are working together on the problem: *How do the parts of the Digestive System work together to carry out the job of the system?* The View is initially empty of content, save for any graphics that have been created on the View. The graphic for this View includes a statement of the shared problem along with a drawing of the Digestive System with colored boxes corresponding to key parts of the system (e.g., the green box corresponds to the mouth, the blue box corresponds to the gullet). Students generate Notes in order to share their ideas, which then appear as Note icons in the View. Students are able to click on the icon of a Note that they wish to read, and the Note will open to show the content. Here we see the content of one Note titled "How do the mouth and gullet work together" where a student has shared the idea: *the mouth and the gullet work together because the mouth chews the food and the gullet helps to push the food done* [down]. Students can also add content (build-on) to any of the Notes in the database, which then appear as Build-On Note icons in the View. A Build-On Note icon has a dot and a connected link to the original Note. As students continue to build on each other's Notes then threads of these icons form on the View.

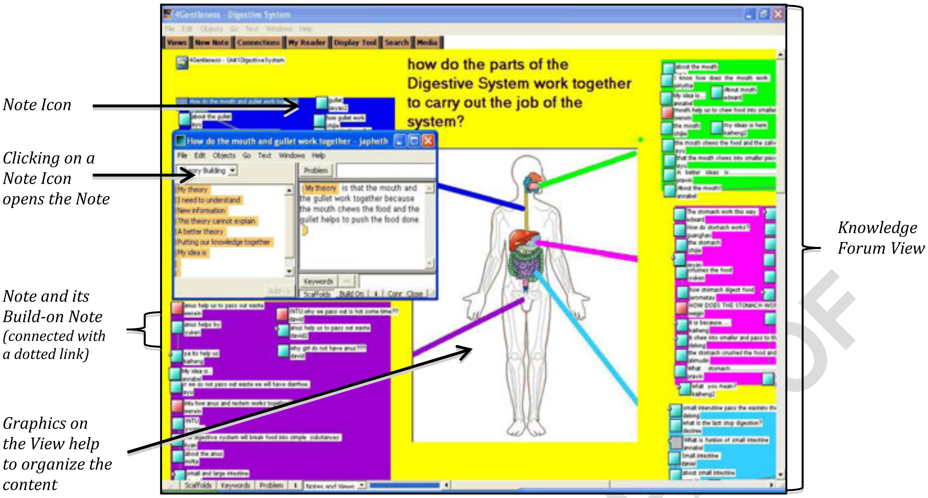


Fig. 2 A Knowledge Forum View with Notes and Build-On's from a Primary 4 database

Even though all of the Note icons that show up on the View look similar, the content of each Note or Build-On can be distinguished by the type of scaffold that a student uses to construct the content. Figure 3 shows an open Note with "theory-building scaffolds." When students contribute content to the community's shared inquiry, they can choose a scaffold that identifies the type of contribution they are making: *My Theory, I need to understand (INTU), New information, This theory cannot explain, A better theory, and Putting our knowledge together*. These default theory-building scaffolds in Knowledge Forum were specifically designed by the developers to support students in advancing their ideas. They are intended to direct learners in ways that support progressive idea improvement without constraining such actions to fixed sequences or "fill-in-the-blanks forms" (Scardamalia 2004, p. 7).

The moves of the Progressive-Improvement Game (Fig. 1) correspond directly with these theory-building scaffolds in Knowledge Forum. In game terms, we can conceptualize the Knowledge Forum view as a "game board." The Notes and Build-On's can be viewed as "game-pieces" that can be used to make moves on the game board. Playing the Progressive-

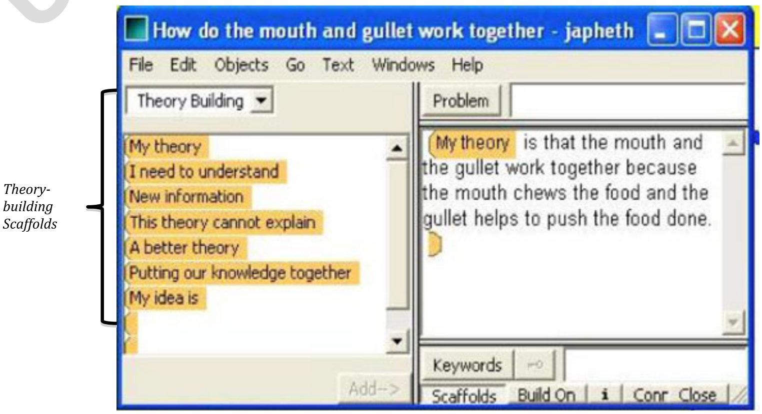


Fig. 3 A Knowledge Forum Note showing the default Theory Building scaffolds

Improvement Game involves making knowledge-building moves intended to advance understanding of the problem the community is investigating. For example, in Fig. 2, the community is working on "*How do the parts of the Digestive System work together to carry out the job of the system?"* The open Note shows one student's move, the contribution *"My theory is that the mouth and the gullet work together because the mouth chews the food and the gullet helps to push the food done* [down]". In playing the Progressive-Improvement Game, this same student or another student can build-on to this Note by making a knowledge-building move such as asking a question or by providing new information. If the entire set of knowledge-building moves in the thread is constructed by the same student, then this corresponds to "single-player" epistemic game play. However, if different students contribute knowledge-building moves to advance the work of the original Note, then this corresponds to "multi-player" epistemic game play, which is much more common in Knowledge Forum's CSCL environment (see Fig. 4). It is possible to operate in both ways in Knowledge Forum, with all moves made in the View publicly available to the rest of the community.

The point of the multi-player epistemic game play is that in playing the Progressive-Improvement Game, students do not need to make the full range of moves by themselves. Instead, knowledge advances can be made through interaction with each other's contributions[5]. In order to support such multi-player moves, Knowledge Forum makes available the ideas, questions, and results of investigative work and exchanges to all members of the community. Thus, one student can propose an initial idea, a different student may independently carry out investigative work related to this idea, and yet a different student may contribute an insight that comes from synthesizing the investigative work with the contributions made by others. Playing epistemic games as a collective permits students to participate in the distributed construction of knowledge, which may allow a classroom community to advance further on problems than might be possible by individual epistemic game play alone.

To summarize, the Knowledge-Forum View can be understood as a collective space where game-pieces in the form of Notes and Build-On's can be used to make knowledge-building moves -– actions that players take in order to advance knowledge given a particular board configuration. Knowledge-building moves in accord with the Progressive-Improvement Game are more strategic than others, and lead to higher-quality game play. Because the game pieces and their configurations on the game board provide concrete, point-at-able visualizations of the community's knowledge work, they visually aid discourse concerning "strategic knowledge-building moves." This provides a powerful way for the students and teachers to talk about actions that contribute toward progressively improving the knowledge within a given problem space.

The implementation path that we construct draws from this multi-player epistemic games approach. In the remaining sections of the paper, we investigate how socializing students into playing the Progressive-Improvement Game can be used to support classroom-based enactments of the KBC model. In order to examine our design theories in practice, we present research on *Ideas First*, a design-based research program involving enactments of the KBC model in Singaporean primary science classrooms (Bielaczyc and Ow 2007, 2010; Ow and Bielaczyc 2007; 2008).

[5] Note that we did not speak of "interactions among the players themselves," but instead of "interactions among the player's contributions." In KBC classrooms, just as in disciplinary communities, the players need not engage each other personally for their contributions to interact and lead to advances in the community's knowledge. Of course, as in disciplinary communities, personal interactions and collaborations among students can also play a valuable role within the classroom community.

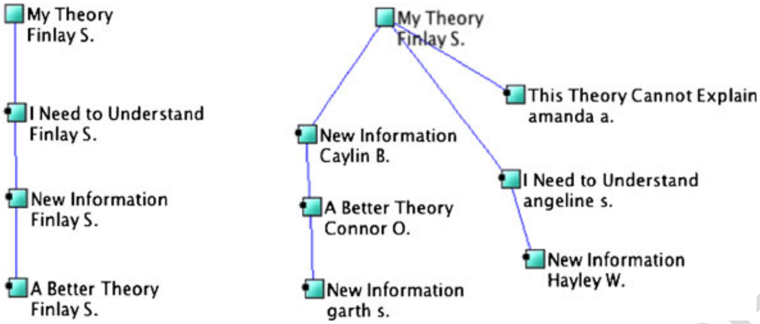


Fig. 4 Single-player knowledge moves *(left)* compared to distributed, multi-player knowledge moves (*right*)

Ideas first: Supporting the enactment of the KBC model in singapore classrooms

Over the past several years we have been engaged in a design-based research program in a Singapore primary school. *Ideas First* is a full 2-year Science program co-designed with primary school teachers that has been operating in 14 Primary 3 and 4 classrooms since 2006 (Bielaczyc and Ow 2007, 2010; Ow and Bielaczyc 2007, 2008). Ideas First was initiated by John Ow, the Science Head-of-Department in Townsville Primary School, as a means of supporting 21st century learning in alignment with the Singapore Ministry of Education's (MOE) *Teach Less, Learn More* policy[6].

We view our role as working together with the teachers (and students and the other stakeholders from the school and MOE) to find ways to engage students and teachers from typical Singaporean primary school classrooms toward creating science classrooms that function as knowledge-building communities. In Ideas First, Scardamalia's (2002) knowledge-building principles were central to the design process. Prior to the project, science lessons were scheduled in 30-min periods where topics were segmented into short presentations and related problem sets. Given the high-stakes nature of the Singaporean exam system, the focus tended toward "coverage" of key topics and practice on exam-type questions with "model answers." Based on the knowledge-building principles, the lessons were restructured into extended inquiry involving students working collectively to advance the classroom community's understanding with regard to specific problems (e.g., *Why are flowers important to plants? How do living things grow?*)[7]. Students' ideas became the centerpiece of the curriculum ("ideas first"), with the intention of shifting toward treating ideas as objects to be worked with and improved.

Engaging students in the progressive improvement of ideas

Although Knowledge Forum has been designed with particular affordances to support idea improvement, the developers point out that actually engaging students in the progressive improvement of ideas can be difficult. According to Scardamalia and Bereiter (2006), "generating ideas appears to come naturally to people, especially children, but sustained effort to improve ideas does not" (p. 100). The challenge involves both "developing a disposition to

[6] This Ministry of Education policy emphasizes curricular depth over breadth.
[7] It should be noted that the Ideas First curriculum maintained the original curricular objectives. However, "coverage" was not achieved through a linear sequence of topic-by-topic alignment to curriculum guidelines, but rather a more interconnected approach. Lampert (1996) details such approaches to curriculum coverage.

work at idea improvement" (p. 100), as well as developing strategies that enable participants to actually advance their ideas. In Ideas First we focus on creating a classroom culture in which these dispositions and strategies are part of the classroom norms and practices. The goal is for idea improvement to become part of "what we do around here" and to foster strategies for making knowledge-building moves through community actions.

As a starting place for such culture building in Ideas First, the first day of Primary 3 Science class opens with a whole class discussion of "How do Scientists make sense of the world?" The discussion highlights the underpinnings of Ideas First, such as working as a science community to understand questions that we have about the world and how, like Scientists, we keep working to improve our ideas and explanations. The importance of situating epistemic games within the culture of a community of practice is similarly highlighted in Shaffer's work on "epistemic frames" (Shaffer 2006). Shared understandings (e.g., practices, knowledge, identity, values) within the community shape and help support (i.e., "frame") the epistemic game play engaged in by participants.

These early discussions about the parallels between Ideas First classrooms and the Science community are supported by the *We Work as a Science Community* Handout (Fig. 5). This initial handout has several key elements. The handout shows photos of students from the school carrying out investigations along with the quote "I am doing my part in a community that is making progress on important problems."[8] The intention is to signal students' social identity within knowledge-building classrooms: *we can work together on problems and carry out investigations in many different ways*. The handout also presents parallels between the students' work and how Scientists make sense of the world. In order to initiate conversation about the Progressive-Improvement Game, the theory-building scaffolds from Knowledge Forum are introduced as part of a process for how to "answer questions that we have about the world."

In order to learn how to make strategic knowledge-building moves that allow students to "work as a science community," it is critical to work together toward understanding knowledge building itself: *What do we mean by "improving an idea"? How can we work together to advance our understanding?* Insight into critical events and features contributes to developing an epistemological perspective on community practices and an understanding of the moves, constraints, and strategies for working with various forms of knowledge (i.e., epistemic fluency). To gain such insights, students and teachers need a means for making visible and reflecting upon knowledge-building processes in an accessible manner. Although Knowledge Forum provides a public space that captures the knowledge work of the community and makes it available for such reflection, we have found that when students and teachers are new to the KBC model that it can be difficult for them to "see" the critical events and features in Knowledge Forum (refer to Frederiksen et al. 1998 for similar findings in teacher video clubs). That is, in Knowledge Forum the game play progresses rapidly and the pace of contributions varies across students. We became interested in designing ways to slow down this process in order to provide the ability to engage step-by-step in one sequence of knowledge-building moves. Focusing the entire class on one move at a time is intended to provide an opportunity to examine the moves made by all members of the community and for students to compare and contrast different knowledge-building moves and the reasoning behind them. Students may also come to see more clearly how their ideas can be used by other students to progressively improve an explanation.

Thus, we became interested in designing tools that would provide a lens for investigating the work of the knowledge-building community (both online in Knowledge Forum and

[8] Quote adapted from Bereiter (2002).

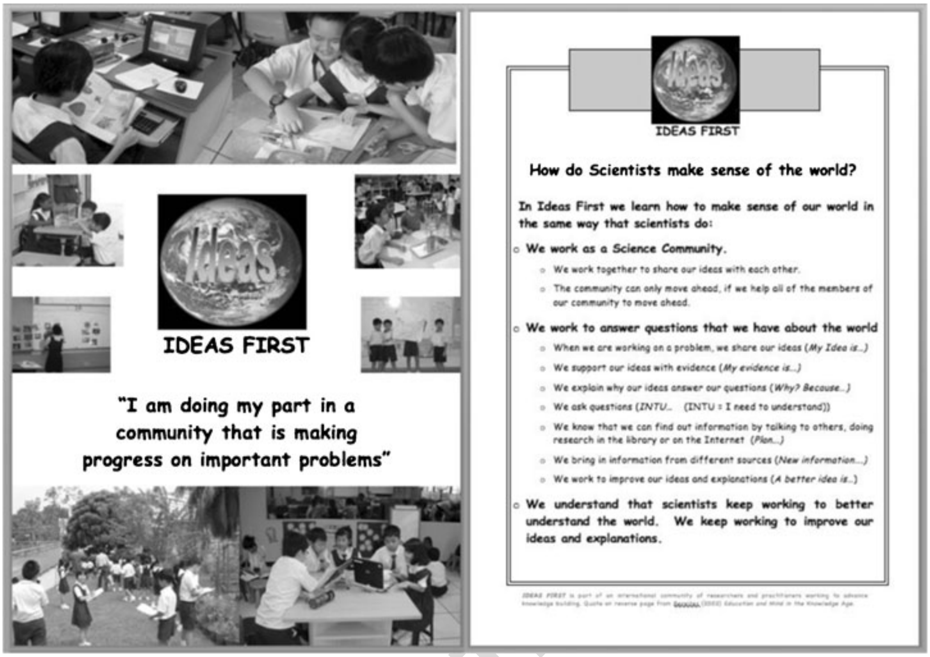


Fig. 5 We work as a Science Community Handout (2-sided handout)

offline). Specifically, we wanted to make visible key aspects of the processes involved in the progressive improvement of ideas. Toward this end, we created two specific types of scaffolding tools that isolate parts of the full Progressive-Improvement Game for practice and reflection: *Think Cards* and *hypothetical game-configurations*. The Think Cards are used in the first half of Primary 3 (Fig. 6). The hypothetical game-configurations are used when students move to using Knowledge Forum in the remaining half of Primary 3 and all of Primary 4. We describe each of these epistemic game scaffolding tools, in turn, below.

Think cards: Learning to make knowledge-building moves

The Think Cards support actions consistent with the Progressive-Improvement Game by focusing on an *initial idea-new information-improved idea* sequence of knowledge-building moves (Fig. 7). The goal is to challenge the prevailing classroom culture where students'

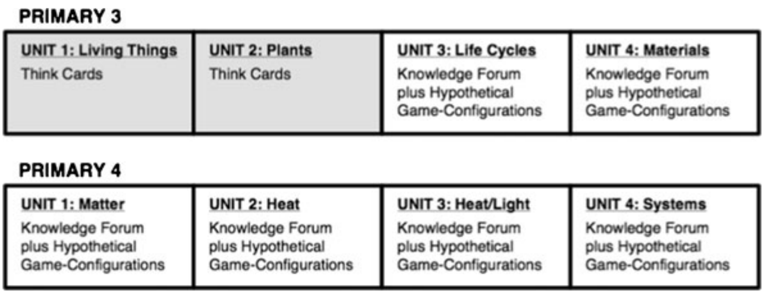


Fig. 6 Use of epistemic game scaffolding tools across Primary 3 and Primary 4

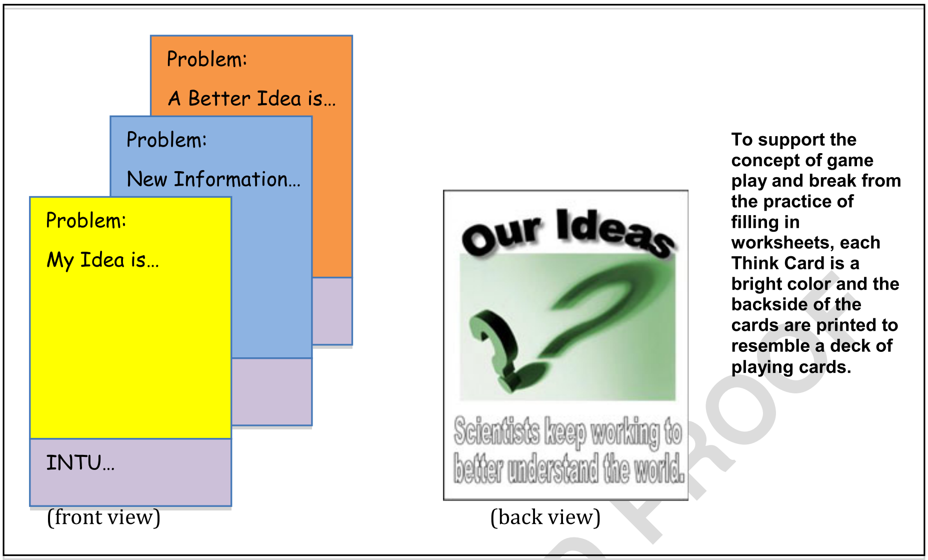
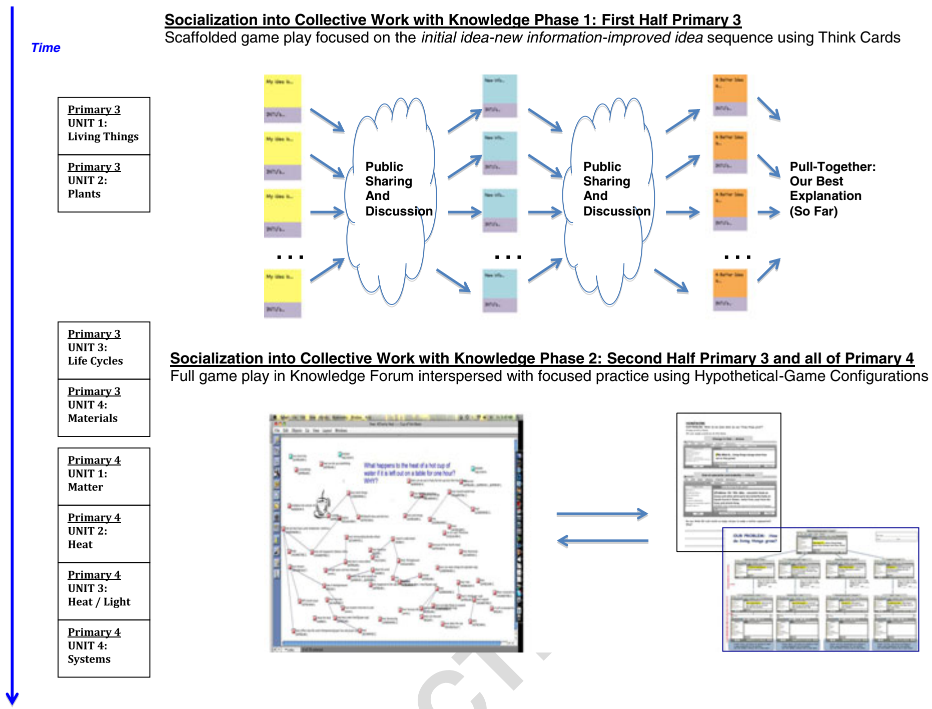


Fig. 7 Ideas First Think Cards

written responses tend to be viewed as static entities that either correctly match a predetermined model answer or are "wrong." This is done in multiple ways. First, the Think Cards introduce a multi-step process that extends over multiple days or weeks. In addition, the Think Cards physically reify students' explanations (*My Idea is…*), the new information that they bring to their inquiry (*New information…),* questions that drive their inquiry (*INTU* stands for "I need to understand"), and improvements that they make to their explanations (*A Better Idea is…*). Further, each child can physically accompany the written form of his or her idea into a group discussion, thereby disrupting the conception that a written idea is a static response to a question when the child holding the Think Card is asked by peers to further elaborate the idea or the child defends the idea when it is challenged. Such oral interactions may also help set the foundations for the back-and-forth of multi-player knowledge-building moves.

Within each unit, the class works together on Problems such as "why are flowers important to plants?"[9] The first Think Card, *My Idea is…*, is used to encourage students to write down their initial explanation for the problem. These, *My Idea is…* Think Cards are then shared in the public space (via the visualizer or whiteboard for the whole class, or in small-group discussions) in order to make visible the diversity of ideas that are now available as resources for members of the community (Fig. 8). In essence, what begins as "My Idea is…" becomes "Our Ideas are." To support such sharing, teachers work to create what Scardamalia (2002) refers to as an atmosphere of "psychological safety" –- setting the classroom norm of respect for others' ideas.

[9] Students work on a *common* problem of understanding that is provided to the whole class in order to address curricular time constraints due to high-stakes testing. In Singapore, the school year comprises four 10-week terms. In this school there were 2–2.5 h of Science scheduled per week in Primary 3 and 4, and an exam period at the end of every term. There is also a national curriculum specifying science objectives to be covered in preparation for the Primary School Leaving Exam (PSLE), a national exam given at the end of Primary 6.



Q4 **Fig. 8**

The *New Information…* Card is used to introduce a possible knowledge-building move toward progressively improving initial ideas. Rather than using resources to "find the answer," the focus is on using books, videos, the Internet, activities, and other people as resources for information that can help in creating an explanation for the problem. In many classes, students begin bringing resources from the public library and home to share with the class. The students' work from these cards is also shared in the public space at various points across the course of the investigations (Fig. 8). Class discussions center on issues such as why certain resources are useful (with some classes discussing the trustworthiness of science content in sources such as children's cartoons and television shows) and the mechanics of note taking, which is a new skill for these 9-year olds. Discussions also include the practice of citing sources in order to return to particular resources if necessary.

The use of the Think Cards occurs over multiple science periods across 8–10 weeks. The initial idea cards lead into research with various resources to collect new information centered on the class problem. During their investigations, students generate as many *New Information…* Cards as they wish. Their work then culminates in *A Better Idea is…* Card, where students are meant to synthesize their learning into an improved explanation for the problem. Finally, the whole class shares the improved ideas from the *A Better Idea is…* Cards in order to "pull-together" the explanation the class has generated for the problem at this point in time (Fig. 8). Because all three cards are repeatedly shared with other class members through whole-class and small-group discussions, the game play is able to extend beyond individual knowledge moves to permit the exchange of student work across cards.

The Think Cards make visible the diversity of ideas that students generate for a particular problem of understanding and that can be collected from various resources, and the multiple pathways possible in moving from initial ideas to the construction of new knowledge. In this way, the Think Cards open up a space for discourse concerning the meaning of idea improvement. Reflecting on the moves students make with the cards provides a means for more deeply understanding the practices of knowledge-building communities.

Investigating students' work with think cards

We were interested in whether the students were able to use the Think Cards as supports for improving their ideas. Here we examine students' first experience with the Think Cards as they work on the common problem for Unit 1: *How do we know if something is a "living thing"?*

The data set includes Think Cards for a single unit in Primary 3 classes for a given year. During the first year of implementing the Think Cards, the cards were not collected back in all classes, so the present analysis focuses on the second year of using Think Cards when we were able to secure a more complete data set. In the second year, one teacher did not collect back the cards and one class did not complete the *A Better Idea is…* Card for the unit, as the teacher reported running out of time prior to the exam period. Therefore the data set comprises Think Cards from six Primary 3 classes. We focused only on Think Cards for which we had the complete *initial idea-new information-improved idea* sequence of cards. The data used for the analyses involved Think Card sequences from 187 students (21 of 208 students were excluded for incomplete sequences).

The content of the Think Cards for one student is shown in Fig. 9. For the initial *My Idea is…* Card, the student generated four ideas (*living things need air, food, and water; they can move, eat, and talk; living things are mammals because they give birth to young; they can grow*). All four of these ideas would be considered as making a contribution to explaining the problem, even though some of these ideas apply to only a small subset of living things (e.g., talking, giving birth to young). That is, when a knowledge-building community is working on a problem for which the canonical explanations *are not known to the community*, the work involves working together to investigate the plausibility of the diversity of explanations generated by community members. Even though some of the proposed ideas may turn out

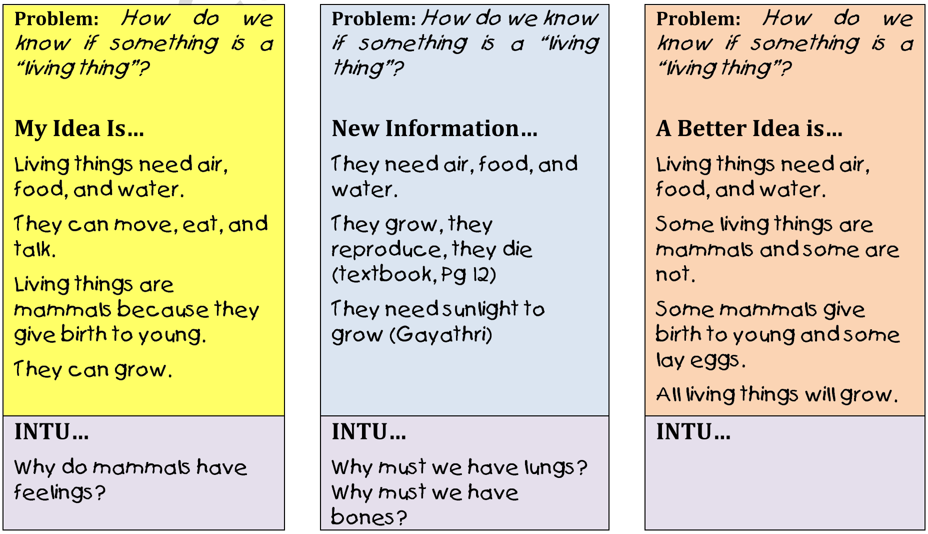


Fig. 9 Example of one student's Think Cards for Unit

to better explain the problem than others, the process of determining the plausibility and contribution of each proposal can contribute to overall community understanding. Thus, even though "talking" is not a characteristic of all living things, working together to discuss whether this characteristic applies to a variety of known living things (humans? parrots? plants? insects? Koko?), can engage students in powerful epistemic practices (e.g., finding evidence, generating contradictory cases, explanation refinement) and help to advance the community's explanation for the problem.

For the *New Information…* Card, the student has listed three pieces of information. One, *they grow, they reproduce, they die,* includes a reference to a specific page of the science textbook. Unit 1 includes specific lessons focused on how to use textbooks as a source of information, which was reflected in several of the students' cards. Another, *they need sunlight to grow,* includes a reference to a classmate named Gayathri. This peer reference may have come from a personal conversation, small-group work, or a whole-class discussion.

For the *A Better Idea is…* Card, the student has written four ideas. Two ideas, *living things need air, food, and water* and *all living things will grow*, have been consistently stated across all three Think Cards. The student writes two improved ideas, the first, *some living things are mammals and some are not* improves the initial idea that *living things are mammals*; the second *some mammals give birth to their young and some lay eggs* improves the initial idea that mammals *give birth to their young.* It is important to note that the ideas in the *A Better Idea is…* Card would not be marked "correct" if they were responses to questions on a worksheet modeled on examination papers. For example, the idea *some living things are mammals and some are not* would not be given full marks because it fails to list the other groups of living things in the syllabus, leaving out "insects," "birds," "plants," and "fungi." However, the student's particular line of inquiry appears to be focused on mammals, and the move from *living things are mammals* to *some living things are mammals* is an improvement. Several of the ideas in this student's *A Better Idea is…* Card show greater clarity as to whether certain characteristics apply to "all mammals" and "all living things." Such distinctions can help the community to better understand the problem and provide opportunities for further inquiry and improvement.

This student has also used the Think Cards to record several *INTU's* such as *why do mammals have feelings? why must we have lungs? why must we have bones?* Although the *INTU…* section on the Think Cards is intended to encourage students to generate questions that help them to deepen their understanding of the problem under investigation, this student and many others also used the space to record a variety of questions of interest or wonderment.

Use of the think cards to make appropriate knowledge-building moves In examining the initial ideas that students generated for the *My Idea is…* Card for Unit 1, it is important to understand the context in which the common problem of understanding was set. In the class prior to the introduction of the *My Idea is…* Card, students observed tanks of fish. The tanks contained live fish and toy fish. Students observed the fish and created classification trees based on a variety of characteristics. For example, some of the live fish and toy fish had striped bodies, so one classification tree created by students had the categories "bodies with stripes" and "bodies with no stripes." In the subsequent lesson, the community problem is framed by presenting a case where a friend is confused by the classification of the fish into "living things" and "non-living things." The friend wonders what it means to be a living thing, so the class community is asked to work on the problem of explaining "*How do we know if something is a "living thing"?*" The problem itself was framed in general terms, however it was grounded in the fish context in order to draw from students' own experiences. In encouraging students to generate ideas that help the community to construct an explanation for the problem, we found that if students struggled to express their ideas in general terms, teachers encouraged students to generate ideas based on the concrete case of the fish. Most students expressed their ideas more generally (as shown in Fig. 9), however we also analyzed the cards for general (living things) versus concrete (specific to fish) expression of ideas.

One of the central interests that we had in analyzing the Think Cards was whether students were using the cards to carry out appropriate knowledge-building moves as they worked to generate explanations for the problem. Because this was the students' first time generating knowledge-building moves, we were interested in the types of moves made by students at each step of the *initial idea-new information-improved idea* sequence.

In order to examine the knowledge-building moves students made with each card, we developed a two-step analytic process. We used this approach because students tended to generate multiple ideas on each card (as shown in Fig. 9). In the first step, we categorized each individual entry on a given card as a valid or invalid knowledge-building move. In the second step, we then used these individual entry categories to characterize each Think Card as a whole.

For the first step in analyzing the *My Idea is…* Cards, we determined whether a particular entry constituted an initial explanation for the problem. For the *New Information…* Cards, we determined whether a particular piece of gathered information could help in explaining the problem under investigation. Three categories emerged:

- *Contributes to the explanation of the problem.* For example, "Living things will grow from small to big," or "Living things need air, food and water."
- *Contributes to the explanation of why fish are living things.* For example, "Fish in tank 1 can move, but Fish in tank 2 cannot move," or "The fishes in Tank 1 can die but the fishes in Tank 2 can't die."
- *Not related to the problem and does not contribute to the explanation.* For example, "If a bird cannot fly, the bird must stay in the bird nest," or "The Venus Fly Trap traps very small animals."

For the first step in analyzing the *Better Idea is…* Cards, we determined whether a particular entry contributed an improved explanation for the problem. Three categories emerged:

- *Idea that improves the explanation of the problem.* Ideas that improve the explanations for the problem included ideas that:

  ○ synthesized ideas of information into overarching concepts, (e.g., a student's initial idea that "living things swim, fly and walk" can be synthesized as "living things move").
  ○ generalized initial ideas such that they were applicable to all living things (e.g., a student's initial idea was specific to fishes "there was something to help the fish get oxygen in tank 1 and the fish can swim," while the improved explanation of this ideas was the generalization of the characteristics observed in fishes to living things, "Living things need air…").
  ○ provided additional information or evidence in support of a claim, (e.g. a student's initial idea was "It can grow" referring to a characteristic of living things, while the improved explanation elaborated on this characteristic providing evidence to support the idea "Living things can grow (Luke). Evidence: Small plants grow into big plants. Babies grow bigger to become adults.")

- *Ideas that further contributed to the explanation of why fish are living things.*
- *Idea that does not improve the explanation of the problem.* Ideas that do not improve the explanation for the problem included ideas that

○ repeated ideas in the *My Idea is*… Card, (e.g., the same ideas about living things "Can move, can write, can blink the eyes, it can talk and it can walk" was repeated in the *My Idea is… and A Better Idea is*… Cards).

○ added more information but did not contribute to furthering the explanation of the problem, (e.g., some ideas a student had in the *My Idea is*… Card were "A snake is a living thing but it has no legs. A piece of paper is not a living thing because it does not need what the human needs…." and in the *A Better Idea is*… Card more information was added that did not improve the explanation "Clouds moving across the sky are non-living things. Worms are living. Flowers are living. Computer that can talk are non-living. The sun is non-living.").

The second step in the analysis for all three cards involved categorizing each student's card as a whole. In order to accomplish this, the categories corresponding to each entry on a given card were then used to classify the number of ideas corresponding to generating a valid knowledge-building move.

In one class, the *A Better Idea is*… Cards were all the same. The teacher for this class explained that since her class is a low-performing class that she did not think that her students would be able to generate better ideas on their own. Instead, she worked with the whole class to generate better ideas for the problem, with each student copying the result of the discussion onto their *A Better Idea is*… Card. We excluded this class from the *A Better Idea is*… Card analyses, as we wanted the table to reflect the results of student efforts in using the Think Cards.

Table 1 presents the results of the analysis. Two independent coders were trained to apply the coding scheme to the Think Cards, with 92 % agreement across the entire corpus. Full agreement on the corpus was achieved through discussion. In examining students' use of the *My Idea is*… and *New Information*… Cards, the majority of students were able to generate ideas that corresponded to valid knowledge-building moves, 87.7 % and 89.8 %, respectively. For the *A Better Idea is*… Card, the results are more mixed. The analyses suggest that only 25.7 % of students are able to generate valid knowledge-building moves involving idea improvement, with roughly the same proportion of students unable to improve upon any of their ideas (23.7 %). The other students appear to be somewhere in between. The analyses also indicate that the students who started out generating ideas specifically about fish moved on to generating more general ideas about living things after a whole-class sharing of the *My Idea is*… Cards and gathering new information.

Students' citations of sources of information We further analyzed the *New Information*… Cards in order to better understand students' citation of resources. As seen in Fig. 9, as students collected information, some cited sources such as other people (typically classmates,

Table 1 Students' use of the Think Cards to generate knowledge-building moves

	Type of knowledge-building move			
Type of Think Card	Most ideas contribute to a relevant KB move	Only some ideas contribute to a relevant KB move	The ideas contributed are specific to fish	None of the ideas contributed to a relevant KB move
My Idea is… Card	(164) 87.7 %	(1) 0.5 %	(18) 9.7 %	(4) 2.1 %
New Information… Card	(168) 89.8 %	(5) 2.7 %	(2) 1.1 %	(12) 6.4 %
A Better Idea is… Card	(39) 25.7 %	(75) 49.3 %	(2) 1.1 %	(36) 23.7 %

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but sometimes others such as teachers and parents) and resources such as textbooks, movies, or websites. In this first unit on Living Things, the primary resources listed by students were either classmates or textbooks. The results of analyzing students' citations of information sources in the *New Information…* Cards are presented in Table 2. The majority of students (71.1 %) cited sources of information in their *New Information…* Cards: 62 students (33.2 %) cited only the textbook, 26 students (13.9 %) cited only classmates, and 45 students (24 %) cited both classmates and the textbook. Roughly a quarter of the students (28.9 %) did not cite the sources for the information collected on their *New Information…* Cards.

Students' questions in the INTU section of the cards We also examined the questions that students posed in the INTU section of the Think Cards. The questions were coded for their potential contribution to explaining the problem. Three categories emerged from the analysis of student responses:

- *Questions that potentially contribute to explaining the problem.* For example, "Why do living things need water?" and "Why do living things respond to changes?' These questions have the potential to improve ideas by deepening an explanation of why an organism is a living thing.
- *Questions of wonderment.* For example, "How does a mimosa plant close up?" and "Why does a stone fish look like a stone?" These questions do not improve ideas explaining why an organism is a living thing. Rather they are questions focused on students' interest about specific characteristics of an organism.
- *No questions posed.* The results of analyzing the types of questions that students generated in the INTU section of the Think Cards are presented in Table 3. Most students did generate questions in the course of using the Think Cards (84.5 %), some that had the potential to deepen understanding of the specific problem under investigation (85 students (45.5 %)), with others focusing on questions of more general interest (73 students (39.0 %)).

Discussion of the think card analyses

It appears that even in the first unit, the Primary 3 students were able to make many valid knowledge-building moves. In examining the *My Idea is…* and *New information…* Cards, we found that the majority of students were able to generate initial ideas for the problem and collect information that could be used in constructing an explanation. Further, most students cited the sources of their information. Incorporating the ideas of others into one's investigation may lead to valuing the contributions made by others, which is important in multi-player epistemic game play in Knowledge Forum.

The analyses of the *A Better Idea is…* Cards indicate that far fewer students were able to improve their ideas than were able to generate initial ideas or collect new information. These results are consistent with Scardamalia and Bereiter's claim that "generating ideas appears to come naturally to people, especially children, but sustained effort to improve ideas does not" (Scardamalia and Bereiter 2006, p. 100). Through repeated experiences with the Think Cards

Table 2 Students' citations of information sources in the New Information… Cards

	Textbooks only	Classmates only	Classmates & textbooks	No citations of source
Citations provided	(62) 33.2 %	(26) 13.9 %	(45) 24.0 %	(54) 28.9 %

Table 3 Students' generation of questions in the INTU section of the Think Cards

	Most have potential to deepen understanding	Some have potential to deepen understanding	Questions of wonderment	No INTU
Questions generated	(34) 18.2 %	(51) 27.3 %	(73) 39.0 %	(29) 15.5 %

and focused reflection on students' contributions to the *A Better Idea is*… Card, the intention is to help students acquire a feel for this move and develop strategies for improving ideas. In the next set of analyses on hypothetical game-configurations (below), we are able to examine the effects of repeated experiences.

The analyses of the *INTU*'s indicate that students are also developing the capacity to generate questions that help them better understand a problem. Although a large number of students' questions were questions of wonderment (e.g., *why does a cheetah run so fast?*), rather than questions directed to the specific problem under investigation (e.g., *why does the animals need food, water and air but why tables and chairs do not need?*), wonderment questions themselves have value in engaging students' interest in science and may provide paths for personal investigation. Based on the analyses, we were not able to determine whether students are unable to generate questions directed to the specific problem, or whether they write their questions of wonderment in the section for INTU's because they have no other place to write their personal questions. As our work progresses we want to be sure that students understand the differences between question types and perhaps use varying prompts in order to support them.

Overall, the Think Cards data indicate that students within each class generated both valid and invalid knowledge-building moves at each step in the *initial idea-new information-improved idea* sequence. There were also differences in the content of students' ideas. This diversity across students' contributions can be used to support our central design goals for the Think Cards, namely to make visible a variety of knowledge-building moves in the Progressive-Improvement Game and to create a space for discourse about idea improvement.

Hypothetical game-configurations: Interspersing isolated practice with full game play

Students used the Think Cards only in the first half of Primary 3. They then moved into full-game play in Knowledge Forum starting in the second half (see Fig. 8). As described above, Knowledge Forum itself provides a rich means for reflecting on key aspects of knowledge building. To complement this, we wanted to provide a way for students to continue to practice and discuss specific elements of epistemic game play (e.g., making a build-on that advances an idea). Hypothetical game-configurations were used to support such focused practice across the Primary 3 and Primary 4 years. Applying the game metaphor, we used a parallel to sports teams where both full-length games and targeted practice sessions are a continual part of a player's development. Similarly, our approach in Ideas First was intended to support a continual cycling of full epistemic game play online in Knowledge Forum and isolated practice of particular knowledge-building moves offline using hypothetical game-configurations.

Classes worked on various hypothetical-game configurations during the second half of Primary 3 and throughout all of Primary 4. Figure 10 shows one of the hypothetical game-configurations used in Primary 3 for the class problem: *What do we mean when we say "living things grow"?* The configuration shows a hypothetical Knowledge Forum Note and a Build-on written by imaginary students Ariana and Chi Lok, respectively. Students were asked

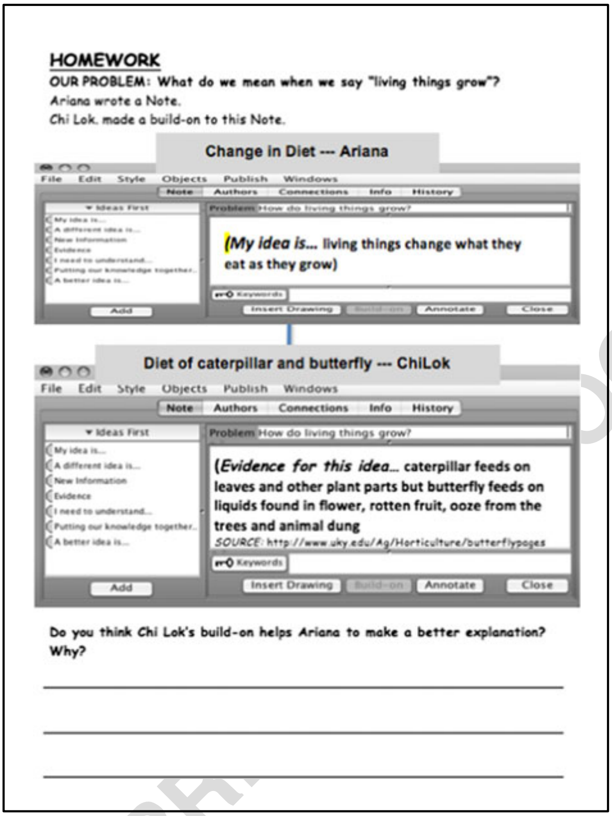

Fig. 10 Hypothetical game-configuration used in Primary 3

whether they think that Chi Lok's build-on helps toward making a better explanation. Examples of student responses in this case included:

- *Yes, he gave Ariana's idea an example of an animal that change what they eat as they grow.*
- *Yes, she explain more on the detales* [details].
- *Yes. It is because Chi Lok says things related with Ariana note. Example Ariana say living things change what they eat as they grow and Chi Lok repled* [replied] *that caterpillar eat different thing and butturfly* [butterfly] *too.*
- *No, because butterfly don't eat animal dung and rotten fruit.*
- *No, Ariana is talking about all living things while Chi Lok's is talking about caterpillar and butterfly.*
- *No. Because she should use her own brain to do her work.*

Student responses to the configuration in Fig. 10 are not intended to be "checked for correctness," but rather to serve as a means for grounding community discourse about game play in concrete contexts. The diversity in student perspectives provides a rich set of ideas to interrogate further. For example, the responses shown could seed a discussion concerning helpful knowledge-building moves. The response ... *because butterfly don't eat animal dung and rotten fruit* may raise the question "What if someone contributes information that you disagree with?" Or the response ... *he gave Ariana's idea an example*... may lead to discussing the usefulness of examples to support an explanation. Further, the statement that … *she should use her own brain to do her work* could initiate community discussion regarding the norms of classroom culture, such as "why might we want to (or not want to) share our ideas and work together?"

Hypothetical game-configurations were typically used to support the students and teacher *within* a particular classroom in reflecting on their epistemic game play. Teachers could tailor the hypothetical game-configurations to show specific configurations drawn from their class's game play in Knowledge Forum –- essentially "freezing the game board" in order to examine particular contexts and discuss existing and potential knowledge-building moves.

We also wanted to provide a way for the students and teachers *across* Primary 3 and 4 to discuss student development of knowledge building strategies at the cohort level. To aid in such a reflection, we worked with the teachers to co-design hypothetical game-configurations to be used as part of the practical examinations for Primary 3 and 4. The practical examinations were chosen because they did not have the pressure of the "high-stakes tests" given during the mid-point and end of each school year. This atmosphere seemed more conducive to playing with ideas using epistemic games. Using the administration period of the practical examination for the hypothetical game-configurations permitted more uniform data collection from all students at a given point in time. A common administration also provided a shared reflective learning opportunity for both the teachers and students. The teachers worked together to examine student work on the practical, discussing student responses and comparing knowledge-building moves across the cohort. In addition, each teacher discussed the various knowledge-building moves with his or her class of students.

Investigating students' work with hypothetical game-configurations

We were interested in how the students worked with the various hypothetical game-configurations. Here we investigated one particular cohort's work with the configurations from the practical exam across their Primary 3 and 4 years. Examining the types of knowledge-building moves made by the same set of students across years provides an opportunity to examine the data for evidence of growth.

Figure 11 shows the hypothetical game-configuration created for the Primary 3 practical. The configuration shows a set of hypothetical Notes and Build-on's for students working on the problem: *How do living things grow?* The same format was used for the Primary 4 practical, with a focus on the problem: *How does heat affect different objects in the world around us?*

Students worked on the practical configurations in two parts: (1) evaluating whether a given knowledge-building move contributes to constructing an explanation, and (2) generating their own knowledge-building moves in order to contribute to constructing an explanation. The configuration was printed on A3-sized paper. For the first part, the paper was folded so that the focus was on the top configuration (see Fig. 11a). Students were asked to consider four build-on's to a given Note and to judge whether each of the build-on's contributes toward making a better explanation (e.g., *Does this build-on help Ariana to make a better explanation? Yes/No*). For the second part, the paper was unfolded and shown in full (see Fig. 11b). Students were asked to choose one thread and to generate a build-on that contributed toward making a better explanation (e.g., *Ariana, Priya, and Jamie are working to make a good explanation for the problem. Can YOU MAKE A BUILD-ON to help them?*). Student work with these configurations is explained in more detail below.

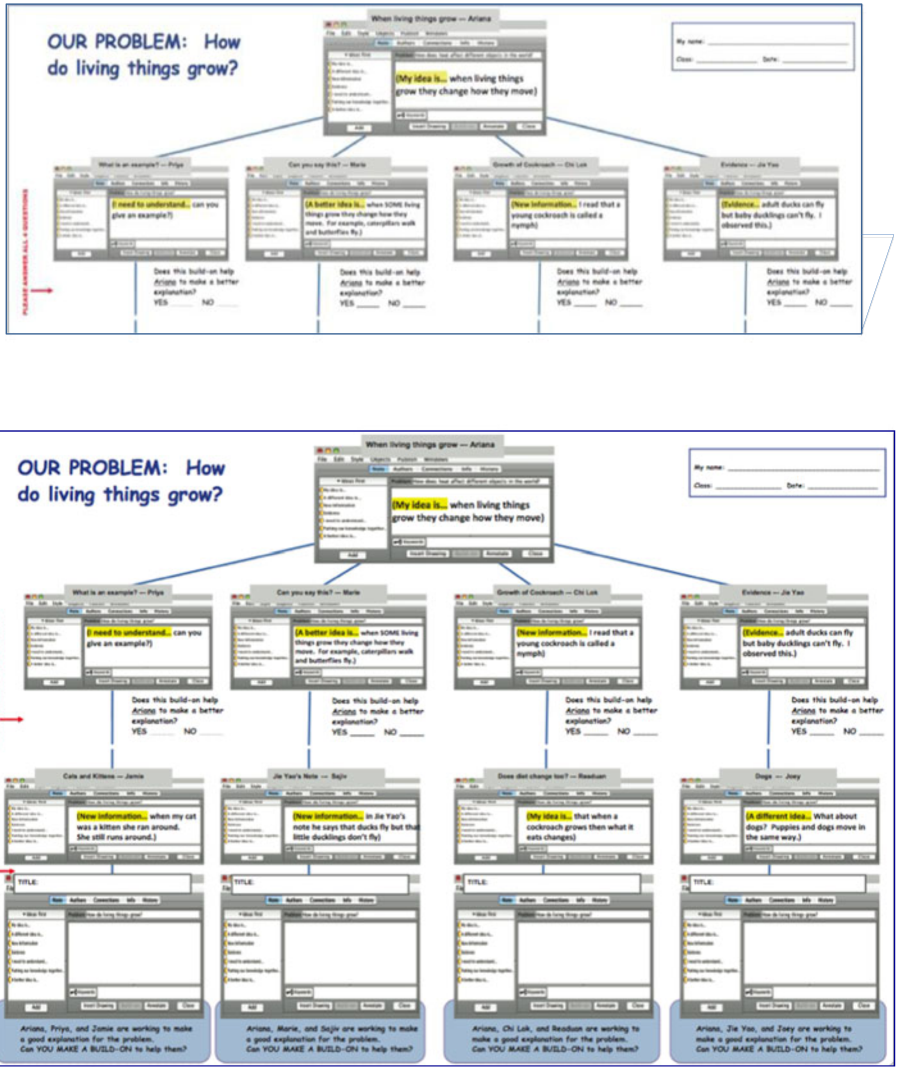

Fig. 11 One of the hypothetical game-configuration used as part of the practical examination

Student evaluations of knowledge-building moves We analyzed students' evaluations of whether a given knowledge-building move contributed to constructing an explanation in the first part of the practical configuration (Fig. 11a). Each build-on corresponded to a particular type of knowledge-building move. The repeated measures across the 2 years involved providing build-on's of the types: *asking an INTU to clarify ideas*, *improving an idea*, and an invalid knowledge-building move of *introducing information completely unrelated to the inquiry*. In order to examine how students handled less familiar knowledge-building moves using Knowledge Forum scaffolds, one of the evaluation items in each year introduced such a move. In Primary 3 students were asked to evaluate a build-on that involved *providing relevant evidence* (using the Evidence scaffold). Primary 4 students were asked to evaluate a build-on *suggesting a different idea*

Table 4 Students' evaluation of knowledge-building moves for constructing explanations

	Primary 3	Primary 4
Recognizing valid moves		
• Asking an INTU to clarify ideas	38.8 %	63.6 %
• Improving an idea	87.5 %	90.1 %
• Providing relevant evidence	65.9 %	
• Suggesting a different idea		47.7 %
Recognizing an invalid move		
• Introducing off-topic information	72.5 %	69.8 %

(using the Different Idea scaffold). Table 4 presents the results of examining student evaluations of the given knowledge-building moves in Primary 3 and Primary 4.

The results suggest that students were better able to identify familiar knowledge-building moves contributing to the construction of explanations in Primary 4 compared to Primary 3. This included moves such as *asking an INTU to clarify ideas* (38.8 % to 63.6 %) and *improving an idea* (87.5 % to 90.1 %). In Primary 3, 72.5 % of students were able to recognize an invalid knowledge-building move. In Primary 4, 69.8 % students identified such a move. A possible explanation for this slight decline may be that the invalid moves involved introducing "off-topic information," and students may have had a more difficult time recognizing off-topic information for a more complex subject matter such as *heat* in Primary 4 than for *living things* in Primary 3.

Student-Generated Knowledge-building moves In order to analyze student ability in generating build-on's in the second section of the practical configuration, we created a coding scheme that characterized the nature of students' knowledge-building moves. Build-on's were categorized as representing either a valid or invalid knowledge-building move, with related sub-categories:

Valid knowledge-building move

○ *Elaboration of ideas in thread:* build-on's that elaborate on the ideas in the thread. For example, if Notes in the thread focus on dogs and how puppies and dogs move in the same way and a build-on elaborates by giving further description of the types of movements: "Yes, puppies and dog move on the same way but when the little puppies run about they will fall down but dogs dosen't."
○ *Broadening of ideas in thread:* build-on's that expand the scope of ideas in the thread. For example, if Notes in the thread are centered on the change in what a cockroach eats as it grows and a build-on broadens the dimensions of cockroach growth to include change in size, "My idea is it do not change what they eat, they change what they look (i.e., bigger)," or broadens the list of example organisms that change what they eat as they grow, "My idea is that the caterpillar eats leaves while the butterfly eats pollen grains."
○ *Proposing a causal mechanism:* build-on's that provide a causal mechanism for certain ideas expressed in the thread. For example, if Notes in the thread provide information that ducks fly but ducklings don't fly and a build-on attempts to explain why this might be the case: "Ducklings never fly because their wings is too small to fly, ducks fly to find food."
○ *INTU/Question asked:* build-on's that ask INTU's or clarifying questions regarding the ideas in the thread. For example, a build-on such as "I need to understand What you mean? Can you give me an example?" Or, if Notes in the thread focus on dogs and how

puppies and dogs move in the same way and a build-on asks a question: "I need to understand Dog how grow."

○ *Instructional help:* build-on's that instruct others on how to make a move or critique elements of the thread. For example, "You are right. But where did you get that information from?" or "Jie Yao is right. All ducks fly but baby ducklings can't fly. Why don't you find out? Maybe you can search the internet or read books."

○ *Direct contradiction:* build-on's that respond to a Note with content "X" with no elaboration beyond contradicting "X." For example, if a Note in the thread contains the idea that "when a cockroach grows then what it eats changes" and the build-on simply contradicts with "cockroach don't change diet."

- *Invalid knowledge-building move*

○ *Unrelated to explanation under construction:* build-on's that do not contain ideas related to the community's work on the problem. For example, in a thread talking about how animals change how they move as they grow with examples given of how ducks and dogs change how they move, and a student builds-on with: "My idea is living things need air, food, water and sunlight" or "New information mealworm have four stages it is egg, larva, mealworm and adult"

○ *Knowledge-telling:* build-on's that add information to a topic in the thread, but the content is unrelated to the community's work on the problem. The term "knowledge telling" is drawn from Scardamalia and Bereiter's research on novice writers. The term describes a writing move where students simply generate content related to a topic without attending fully to the requirements of the writing context (Scardamalia and Bereiter 1987). For example, in a thread talking about how animals change how they move as they grow with examples given of how ducks and dogs change how they move, a student builds-on by telling information about the topic ducks and dogs but unrelated to the inquiry: "My idea is they are mammals and dogs eat dog food too" or "After about a few days, a duckling will hatch out from a duck."

○ *Copied content:* build-on's that directly repeat content from one of the given Notes in the configuration.

○ *Blank:* when no content is provided.

Two independent coders were trained to apply the coding scheme to build-on's generated by students in both Primary 3 and Primary 4. Both coders analyzed the 273 build-on's generated in Primary 3 and the 262 build-on's generated in Primary 4, with 89.7 % agreement on the sub-categories across the entire corpus. Full agreement on the corpus was achieved through discussion. The results are presented in Tables 5 and 6.

Discussion of the hypothetical game configuration analyses

The hypothetical game-configurations were designed to complement the epistemic game play in Knowledge Forum by focusing an entire class on specific elements of play. The use of

Table 5 Students' Generation of Build-on's (major categories)

	Primary 3 students	Primary 4 students
Valid Knowledge-building Move	183 (66 %)	247 (94 %)
Invalid Knowledge-building Move	90 (34 %)	15 (6 %)

Table 6 Students' Generation of Build-on's (sub-categories)

	Primary 3 Students	Primary 4 Students
Valid knowledge-building move		
Elaboration of ideas in thread	72 (26 %)	117 (45 %)
Broadening of ideas in thread	33 (12 %)	64 (24 %)
Proposing causal mechanism	48 (18 %)	28 (11 %)
INTU/Question asked	17 (6 %)	34 (13 %)
Instructional help	3 (1 %)	1 (0.3 %)
Direct contradictions	10 (4 %)	3 (1 %)
Invalid knowledge-building move		
Unrelated to explanation	31 (11 %)	1 (0.3 %)
Knowledge-telling	37 (14 %)	5 (2 %)
Copied content	17 (6 %)	6 (2 %)
Blank	5 (2 %)	3 (1 %)

common game configurations as part of a practical examination for all students in Primary 3, and again in Primary 4, was intended to provide a means for examining and discussing student knowledge-building moves at the cohort level.

The results of the analyses indicate improvement across the cohort from Primary 3 to Primary 4. In Primary 3, roughly one-third (34 %) of the students were unable to generate valid knowledge-building moves when presented with a specific Knowledge Forum "game board" and asked to generate a build-on that would help advance an explanation for a given problem. Most of these students were able to generate a build-on, but they tended to use either a "knowledge telling" move (i.e., if the prior Note mentions a certain animal then tell information about that animal) or to provide unrelated information. Because writing something rather than leaving a blank is often rewarded in examination contexts, these moves are strategic, just not strategic as part of multi-player engagement in the Progressive-Improvement Game. By Primary 4, only 6 % of students made invalid knowledge-building moves for a similar configuration.

In moving from Primary 3 to Primary 4, the largest increases are seen in students generating build-on's that elaborate on ideas in a thread (26 % to 45 %), broaden the scope of ideas discussed (12 % to 24 %), and pose questions (6 % to 13 %). The analyses also indicated a slight decrease (18 % to 11 %) in students making the move "Proposing causal mechanisms." It may be the case that as the subject matter increases in difficulty (i.e., from the *growth of living things* to *heat*) that students become less comfortable making moves involving causal explanations.

Although the numbers are small, one interesting category that emerged from the analysis was that of "instructional help." This category refers to when students reflect on strategies for playing the game and the nature of the moves being made. For example:

- *Jie Yao is right. All ducks fly but baby ducklings can't fly. Why don't you find out? Maybe you can search the internet or read books.* (Primary 3)
- *You are right. But where did you get that information from?* (Primary 3)
- *Mealworms do change how they move because when they're beetles they fly, instead of crawling. The earlier notes don't explain anything about moving at all!* (Primary 3)
- *The air has cooled down so the balloon got smaller. You can find it in your textbook.* (Primary 4)

As students improved their ability to make valid knowledge-building moves across Primary 3 to Primary 4, the number of “instructional help” moves decreased. Primary 3 students generated “instructional help” moves such as providing suggestions on how to look for information and the resources that could be used. These helping moves may have been used more in the first year when students were trying to learn how to play the epistemic game and were helping each other to do so. The decrease in the second year may be due to the improved ability of members of the community to independently carry out strategies to support their work with ideas.

Primary 4 students also generated fewer “Direct contradictions” compared to Primary 3. Primary 4 students still made build-on’s where they disagreed with previous content in a thread, however they were more likely to elaborate on the ideas that they disagreed with by providing additional information or evidence.

Because the interactions in Knowledge Forum can become quite involved with various build-on’s and threads of interaction, it is important for students to be comfortable navigating the game space and contributing to play. The results of analyzing students’ game play with the practical configuration across the 2 years suggests that students are becoming better able to work with Notes on the “game board” and join in the multi-player interaction with valid knowledge-building moves.

Science learning in a knowledge-building community: Beyond model answers

In the present paper, we illuminated a potential implementation path for “getting started” in enacting the KBC model in traditional classrooms. The intention was to support students in understanding and becoming participants in the epistemic practices of knowledge-building communities. Our analyses focused on whether the Primary 3 and 4 students improved in their ability to engage in the Progressive-Improvement Game. Although it is beyond the scope of this paper to provide in-depth analyses of the associated shifts in teacher practices across the years of the Ideas First program, we feel it is important to share some insights into this aspect of the work.

The research on science education underscores the importance of actively participating in the epistemic practices of scientists and the governmental policies of many countries, including Singapore, underscore such learning. However, many countries are also driven by high-stakes exams that focus on content knowledge and skills that do not necessarily align with such epistemic practices. Teachers are often caught in between.

In the Singaporean system, students in primary school take a high-stakes national exam at the end of Primary 6, with mid-year and end-year exams in Primary 2 through 5 used for tracking. Thus, the teachers that we worked with in *Ideas First* were understandably driven to have students excel on exams, rather than to become enculturated into the knowledge-building community of scientists. Many felt that it would be “more efficient” to just tell students the model answer and have them practice related exam questions, not to have students generate a diversity of ideas and work collectively to create an explanation. Over time, however, the process of working with a diversity of student ideas came to be seen as a possible way of developing a deeper understanding beyond the model answer.

The teachers worked to co-design the Think Cards, and even though they were aware that the class would work together to improve ideas over time (from *My Idea is…* to gathering *New Information…* to refining *A Better Idea is…*), they still became concerned that the students’ initial ideas did not match the “model answer.” This is not an uncommon “puzzling moment” (Ballenger, 2009) or “teaching problem” (Lampert 1996) –- to overcome seeing students’ ideas Q5/Q6 as "wrong answers" that pose a barrier to deeper understanding to instead working to use the diversity of student ideas as a resource in classroom inquiry. The Think Cards supported a way to publicly share students' ideas and to facilitate interaction as part of a process of progressive improvement (refer to Fig. 8). As teachers started to engage more fully in this process, they began to see that a diversity of ideas could serve as a valuable resource for the class discussion, rather than a setback. Similarly, students were provided a way to work within a communal space of ideas toward progressively constructing an explanation for a problem under inquiry.

As an example, the problem "How do we know if something is a 'living thing'?" was intended to be quite open, unlike the typical exam question for the unit, "Name the characteristics of living things." However, the model answer that teachers said they looked for was the same: *Living things (1) need air, food, and water, (2) grow, (3) can reproduce, (4) can die, and (5) can move by themselves*. Figure 12 shows three *My Idea is…* Cards drawn from one of the Primary 3 classes. Not one of the three cards matches this model answer, although each has ideas that can serve as a resource for class discussion. Such resources include listing characteristics of living things (e.g., *need air, food, and water; can die; can lay many, many eggs*), providing means for testing if something is a living thing (e.g., *if it is moving; if you see bubbles moving out from the fish's mouth*), introducing the use of a classification table, and providing examples of both living things and non-living things. For instance, the statement that "living things can lay many, many eggs" and that dogs, cats, trees, and flowers are examples of living things can be used together to talk about characteristics that apply to all living things or some living things, possibly leading to

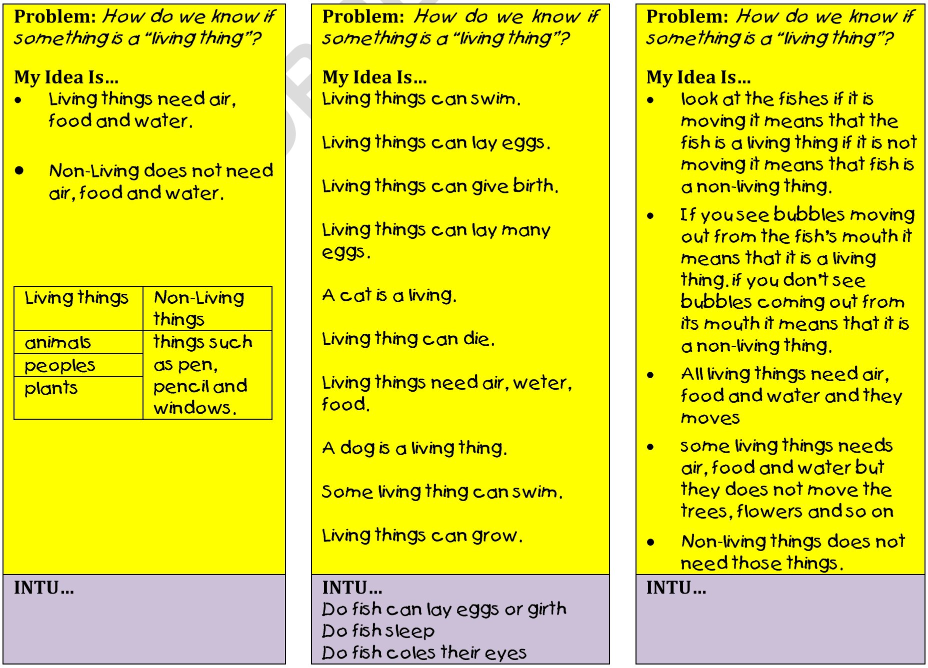

Fig. 12 ***My Idea is…* Cards** from three different students in one of the Primary 3 classes

discussing characteristics in common among dogs, cats, trees, and flowers. Further, looking together across the *My Idea is…* Cards can also lead to teachers and students making plans for gathering new information as part of the next move in the Progressive-Improvement Game. Such plans might include fleshing out certain areas or searching for evidence to support initial ideas.

Similarly, when teachers had students work to pull-together an explanation for the problem under investigation from the *A Better Idea is…* Cards, they found that the diversity of ideas often permitted the class to construct a richer explanation than the model answer (*Our Best Explanation (So Far)* in Fig. 8). For example, for the problem "How do we know if something is a 'living thing'?" the teachers had expected a model answer listing five characteristics. In each class, after students had used the Think Cards across an *initial idea-new information-improved idea* sequence of knowledge-building moves, the diversity of ideas that were available to use in pulling together the community's explanation included not only these five characteristics, but also related evidence drawn from the textbook and class discussions, examples of living things and non-living things, and ways of testing (e.g., some children talked about withholding food or air as a means of testing if something was a living thing). The explanation that is co-constructed from pulling-together from the *A Better Idea is…* Cards is then available to all community members.

One critical shift for teachers involved recognizing that in engaging in the multi-player epistemic game, that each individual student's *A Better Idea is…* Card does not need to result in the same complete and correct explanation. Instead, there needed to be enough advancement made on the Think Cards across all individuals in order for the community to have the resources to draw from in pulling-together a robust explanation. Understanding this aspect of multi-player epistemic game play is aided by drawing upon parallels to the disciplinary culture of Science. Within the Science community, investigation of a common problem tends to lead to a diversity of inquiry processes and results. In turn, these diverse individual efforts provide insights and resources for advancing the community knowledge. This is a powerful epistemological insight, as Ford (2010) points out: "individuals do not construct scientific knowledge, communities do" (p. 269). Some teachers used these parallels to explicitly discuss similarities between student work and the epistemic practices of Scientists with their students.

Although the work with multi-player epistemic games did not erase concerns with high-stakes exams, the teachers came to see that playing the Progressive-Improvement game provided a means for more students to engage deeply with the subject matter through having opportunities to generate and compare ideas, carry out research, and work together to co-construct explanations. In contrast to focusing solely on the model answer, they saw that when student ideas that differed from the model answer were given value in the classroom discussions, more students began to participate in the discussions and develop strategies for improving their initial ideas.

Conclusion

The central goal of our design work was to investigate the development of supportive tools and practices to support a shift in classroom culture and deepen our understanding of critical change processes. We proposed that a powerful means for navigating the needed changes entails conceptualizing Knowledge Forum as a space for playing multi-player epistemic games and supporting teachers and students in learning the moves for playing various knowledge-building games, such as the Progressive-Improvement Game. We designed the Think Cards and hypothetical game-configurations to support learning of the moves of the Progressive-Improvement Game. These scaffolding tools are intended to isolate parts of the full Progressive-Improvement Game for practice and reflection.

In Knowledge Forum the game play progresses rapidly and the pace of contributions varies across students. Both the Think Cards and the hypothetical game-configurations slowed this process and provided the ability to engage step-by-step in one sequence of moves. Focusing the entire class on one move at a time provided an opportunity to examine the moves made by all members of the community and for students to compare and contrast different knowledge-building moves and the reasoning behind them. Students may also come to see more clearly how their ideas can be used by other students to progressively improve an explanation.

In order to examine our design theories in practice, we investigated the use of these tools as part of *Ideas First*, an enactment of the KBC model in Singaporean Primary 3 and 4 science classrooms (Bielaczyc and Ow 2007, 2010; Ow and Bielaczyc 2007, 2008). Our analyses of students' work with the Think Cards and the hypothetical game-configurations indicated that students are able to make a variety of valid knowledge-building moves and that they improve in their ability to generate valid moves as part of multi-player game play over time. Learning how to engage in such multi-player epistemic games provided students a means for working together to advance knowledge as part of a knowledge-building community. Through engaging in such game play, it was also possible for the classroom community to generate explanations that extended beyond the curricula's model answers.

In working with the Think Cards and the hypothetical game-configurations, the students generated ideas and information that serve as resources for classroom discussion. These student-generated resources provided opportunities to carry out comparisons, raise questions, and form syntheses that may deepen understanding and support the class in constructing robust explanations for problems of inquiry. In this way, the diversity of ideas across the cards can contribute to classroom discourse at two levels:

- the subject matter of the inquiry (such as living things)
- the multi-player epistemic game play (the strategies and moves involved in the processes of building knowledge)

Perkins (2013) underscored that learning to be a critical thinker goes beyond just being immersed in a rich learning environment where powerful learning strategies are modeled and engaged in. In addition, there needs to be explicit naming of and discussion of the strategies and their use in order for them to become powerful tools for learners.

The Think Cards and the hypothetical game-configurations help serve as dialogic tools that permit sharing and discussion of particular knowledge-building moves, strategies, and the game itself, as students shift from traditionally individual learning approaches toward understanding each other as contributors to a collective knowledge-building effort. In this way the students can establish a foundation for multi-player game play in Knowledge Forum. Thus, the approach contributes to a theory of trajectories of change, or the creation of an "implementation path" for the KBC model (Bielaczyc and Collins 2006; Collins et al. 2004).

In supporting students in learning to engage in the epistemic game play of knowledge building communities, the work here also contributes to the growing body of research on the development of disciplinary communities in K-12 classrooms (Ford 2010; Herrenkohl et al. 1999; Hogan and Corey 2001; Sandoval, et al. 2000). Deepening our understanding of how students engage in such communal learning processes is critical to advancing developments in the field of CSCL (e.g., Koschmann et al. 2002; Stahl and Hesse 2010).

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