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<td>Katerine Bielaczyc and Manu Kapur</td>
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Playing Epistemic Games in Science and Mathematics Classrooms

Katherine Bielaczyc
Manu Kapur
Learning Sciences Lab
National Institute of Education
Singapore

Education in the Knowledge Age calls for engaging students in creative work with knowledge. A major implication for research and design in the learning sciences is that the necessary shift is not simply technological or pedagogical, but essentially epistemological (Brown, 2007). In this article, the authors view such creative work with knowledge through the theoretical lens of epistemic games (Collins & Ferguson, 1993; Morrison & Collins, 1993). Epistemic games refer to strategies for disciplinary knowledge within complex domains, and are based on the study of disciplinary communities such as Physical, Biological, and Social Scientists. The authors describe two instantiations of epistemic game play drawn from classroom interventions in science, Ideas First (Bielaczyc & Owy, 2007), and mathematics, Productive Failure (Kapur, 2008). The two research projects were funded as part of a comprehensive reform effort in Singapore schools toward 21st century education. Their analyses illustrate the design features of epistemic games in learning environments and discuss the implications of learning to play epistemic games.

Introduction

Education in the Knowledge Age calls for engaging students in creative work with knowledge. In advising the Singapore Ministry of Education on what is needed to achieve the necessary transformations, John Seely
Brown (2007) asserted that the major issues are not technological or pedagogical, but are instead epistemological. Educational change necessitates a reconceptualization of knowledge goals and what it means to learn and, consequently, the design of learning environments.

One useful framework for guiding such a reconceptualization is epistemic games (Collins & Ferguson, 1993; Morrison & Collins, 1995). Collins and his colleagues are concerned with characterizing the ways in which members of a community of practice work to construct knowledge. Epistemic games refer to strategic play with disciplinary knowledge and are based on the study of disciplinary communities such as Physical, Biological, and Social Scientists (e.g., the cost-benefit-analysis game, the systems-dynamics game). The focus is on developing an understanding of the moves, constraints, and strategies for working with various types of epistemic forms, the representations used by disciplines to communicate knowledge work (e.g., stage models, systems dynamics models). The overall goal is to support learners in developing 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 & Collins, 1995, p. 44). Such a framing is consistent with current theoretical perspectives in the learning sciences emphasizing learning as a process of enculturation, with a focus on learning to be rather than simply learning about (Sawyer, 2006; Thomas & Brown, 2007).

We ground our discussion of epistemic games in two classroom-based research projects of the NIE Learning Sciences Laboratory, Ideas First (Bielaczyc & Ow, 2007) and Productive Failure (Kapur, 2008, 2009a,b). The two research projects were funded as part of a comprehensive reform effort in Singapore schools toward 21st century education. The classroom interventions engage students in epistemic game play in the disciplines of science and math, respectively. Our analyses illustrate the design features of epistemic games in classroom environments and discuss the implications of learning to play epistemic games.

The projects exemplify work in the field of the learning sciences as being grounded, as noted above, in theoretical perspectives centered on learning as a process of enculturation, stressing learning to be rather than simply learning about. An important thrust in the learning sciences is to design and examine complex learning environments in an ecologically sound manner, and the two projects aim to do precisely that. By adopting an iterative design research process, the projects seek to unpack the complex dynamics that unfold when designs are enacted in real classroom ecologies; the dynamics that lie at the core of theorizing, understanding, and positively impacting how people learn.

**Playing Epistemic Games in Science Classrooms**

Ideas First is a full two-year science program co-designed with primary school teachers that has been operating in 15 grade 3 and grade 4 classrooms since 2006 (Bielaczyc & Ow, 2007; Ow & Bielaczyc, 2008). The central focus of our research is on how teachers and students navigate the shift from traditional didactic science classrooms to classrooms that function as knowledge building communities, where the emphasis is on progressive improvement of ideas toward collective goals of understanding (Scardamalia, 2002; Scardamalia & Bereiter, 2006). One of the central epistemological shifts in Ideas First classrooms is away from learning as acquisition of facts that are either right or wrong toward treating ideas as objects of inquiry that can be tinkered with, combined with other knowledge objects, and improved. Engaging with ideas as objects of inquiry involves students in epistemic games played in a collective space with self-generated ideas, ideas of others in the local community, and ideas drawn from the wider science community.

In Ideas First, the epistemic games are of two major kinds. The first concerns science representational games involving target structures, such as classification trees and graphs. The second concerns knowledge building games involving goal states, such as improved explanations. The first kind correspond to those described by Collins and Ferguson (1993), where the game involves constructing a fixed representational target, such as playing a Multicausal-Analysis Game with an And/Or Graph. The second are those where there is no specific epistemic form targeted, such as the Theory-and-Evidence Game (Morrison & Collins, 1995). However, in Ideas First, students are provided with concrete "game-pieces" to guide the play of knowledge building games. These game-pieces are based on Knowledge Forum, an online environment designed by Scardamalia and Bereiter to support their Knowledge Building Communities model (Scardamalia, 2004).

One such set of game-pieces is Think Cards (see Figure 1), which are based on Knowledge Forum Notes (Scardamalia, 2004). Scientists advance their understanding of problems in many ways. The Think Cards are meant to support one sequence of knowledge building moves that might be used to advance understanding of a problem—generate an explanation for a problem and then gather new information that can be used to improve this explanation. Think Cards physically reify students' explanations (My Idea is...), the new information that they bring to their inquiry...
The Think Cards are designed to help students engage in a knowledge building culture where ideas are treated as objects available for interrogation and change. They can be seen as physical/abstract knowledge objects in a child’s hand that co-located agents can act upon (months 1–5 of Ideas First), to “concrete” knowledge objects in the virtual space of Knowledge Forum that can be acted upon by multiple agents (months 6–24 of Ideas First), to broader disciplinary knowledge worked upon by members of the science community.

Similar to sports teams, where both full-length games and targeted practice sessions are a continual part of a player’s development, Ideas First involves a constant cycling of action and reflection in learning to play the epistemic games of Science. Think Cards are only one example of the types of artifacts we have designed to support targeted practice in knowledge building moves. Others include hypothetical game-configurations (Figures 2 and 3) that can be used to reflect on the knowledge building moves made.
possible by a particular configuration of knowledge objects. Figure 2 shows a Primary 3 worksheet that presents a hypothetical initial explanation (based on prior student data) generated in response to the problem the students are working on (in this case, What do we mean when we say “living things grow?”). The configuration is meant to support reflection on the types of knowledge building moves that students could make to advance this initial idea. Figure 3 shows a more complex game configuration, presenting not only a hypothetical initial explanation (located at the top of the page) in response to a problem, but also a series of hypothetical knowledge building moves (the threads below (in Knowledge Forum these are called “build-on’s”)). The configuration is meant to support evaluation of the quality of the given moves, as well as to reflect on possible moves that students could make to each thread in order to contribute to the progressive improvement of ideas.

In addition to supporting student engagement with scientific ideas and practices, we have found that such game-pieces and configurations play a role in teacher learning. Our goal is to engage teachers themselves as a knowledge building community through working together to create pedagogical moves and cultivate a classroom culture that supports epistemic game play.

Figure 3. Ideas First hypothetical game configuration (more complex).

Playing Epistemic Games in Mathematics Classrooms
Designing for Productive Failure (Kapur, 2008, 2009a; Kapur & Kinzer, 2009) involves designing conditions for learners to persist in epistemic games as they attempt to solve complex problems without the provision of supportive structures initially. Such game play often results in learners generating and exploring a diversity of epistemic forms (Morrison & Collins, 1995)—representations and methods—for solving the problem, although they are rarely able to solve the problem successfully. In spite of this seeming failure, persisting in the problem-solving process is germane for learning, provided an appropriate form of instructional structure subsequently follows (Clifford, 1984; Schmidt & Bjork, 1992; Schwartz & Bransford, 1998).

Research on productive failure is premised on the assumption that much as it is important for learners to
learn about mathematical concepts and problem solving, it is just as important if not more to engage in the practice like (not exactly the same) mathematicians. Furthermore, learning about mathematical concepts is deeper and more adaptive when it is dialectically tied to engaging students in the practice of mathematics, which is in part characterized by the kinds of epistemic games that mathematicians "play" when solving problems. These games can be seen in the acts of representing problems, developing domain-general and specific methods, flexibly adapting or inventing new representations and methods when others do not work, critiquing, elaborating, explaining to each other, and ultimately not giving up but persisting in solving complex problems (diSessa et al., 1991; Thomas & Brown, 2007).

Strong evidence supporting the efficacy of epistemic games in productive failure (PF) has been found in a series of design experiments with grade 7–9 mathematics students in Singapore public schools (Kapur, 2009a; Kapur & Bielaczyc, under review; Kapur, Dickson, & Toh, 2008; Kapur & Lee, 2009). In this article, we provide an illustration of the process that unfolds when students are afforded the opportunities to play like mathematicians.

The illustration comes from two groups of three students each solving a complex problem on average speed—the targeted concept—without the provision of any instructional facilitation or support. The gist of the complex problem scenario was as follows (for the full problem, see Kapur, 2009a): Two friends, Jasmine and Hady, had to get to an exhibition by a certain time. They could walk and/or ride a bicycle. The constraint was that they had to reach the exhibition at the same time despite having different walking and biking speeds. Furthermore, a little while into their journey, one of the bicycles breaks down, forcing them to re-strategize. Student groups had to determine ways in which Jasmine and Hady could ride and/or walk for different periods of times and distances to reach the exhibition in time.

All groups used graphical, proportional, guess-and-check, and letter symbolic algebraic representations in their efforts to solve the problems. These representations and methods can be seen as epistemic forms or structures generated by the group to solve the problem (diSessa & Sherin, 2000; Schwartz & Martin, 2004). Why are these representations and methods epistemic? It is important to understand that these student-generated representations and methods rely upon students' constructive resources (diSessa & Sherin, 2000) to make meaning of the complex problem. Different ways of representing and solving the problems therefore provided them with different kinds of insights and understanding of the problem and potential solutions and solution paths—a prototypical epistemic activity of engaging in mathematical meaning making. Figure 4 presents an example of the group work artifacts illustrating the diversity of epistemic forms resulting from such meaning making.

Figure 4 reveals that the groups used a diverse but linked set of epistemic forms such as iconic (e.g., house, bicycle), graphical (e.g., straight lines for Jasmine and Hady), proportional (e.g., ratios between Jasmine's and Hady's speeds and distances for walking and riding), tabular, and letter-symbolic algebraic representations (e.g., using numbers and unknowns such as X, Y, A, B to link with other representations). Additionally, the groups also set up systems of algebraic equations, S1 and S2. Furthermore, S1 and S2 were conceptually accurate representations of algebraic representations for solving the average speed problem. However, it is easy to see that the system of equations contained more variables than equations, and therefore remained unsolvable. The use of letter-symbolic algebraic representations is significant because the introduction of algebra in the formal curriculum does not happen until after the unit on average speed. It seemed that the students were able to produce algebraic representations without having had any prior, formal instruction in algebra.

Elsewhere (Kapur, 2009a; Kapur & Bielaczyc, under review), we triangulated these representations with the collaborative group discussions around these representations and methods. Despite producing various insights and inter-connected graphical, proportional, and algebraic representations as well as methods for solving the problem, groups were ultimately unable to succeed in solving the problem. Some of these structures or epistemic forms were rejected quickly (e.g., guess-and-check method) while others were "abandoned" only when further development resulted in an understanding that the structure was either not suitable for the problem (e.g., ratios method) or resulted in an impasse (e.g., algebraic method). More importantly, our analysis revealed that the productive failure design afforded students the opportunities to participate in the mathematical "game" of generating and playing with epistemic forms by representing problems, developing domain-general and specific methods, flexibly adapting or generating new representations and methods when others do not work, critiquing, elaborating, and explaining to each other, and ultimately not giving up but persisting in solving complex problems. Not surprisingly, this game play also afforded students the opportunities to better explore and understand the affordances and constraints of the epistemic forms, thereby preparing them to derive greater benefit from a subsequent well-structured consolidation lesson by the teacher (Schwartz & Bransford, 1998).
In sum, research on productive failure underscores the importance of designing learning in ways that affords students the opportunities to learn mathematical concepts as they engage in the practice of mathematics. A focus on the practice of mathematics entails a strong epistemological shift in how we conceive and design for mathematical learning and problem solving (Kapur, 2009b).

Discussion

In this article, we leveraged the theoretical lens of epistemic games to illustrate designs that support epistemic game play for learning. The two projects—Ideas First and Productive Failure—illustrate two different facets of designing for epistemic games.

The Ideas First project illustrates the design of concrete artifacts to support and mediate epistemic game play, whereas the Productive Failure project illustrates the process that unfolds when students are afforded the opportunities for such game play. Both facets are important and exemplify different angles of a comprehensive design effort toward supporting epistemic game play in Singapore classrooms, and learning environments in general.

Although our argument foregrounds the role of epistemic games, it is not to be taken as argument for undermining the role of content knowledge and skills. Instead, our argument is one for grounding the learning about a discipline in a context or an environment that affords students the opportunities to learn to be like a member of that discipline, that is, engage in the practices, e.g., epistemic games, of the discipline. Note that this is in stark contrast to the popular and commonly practiced notion of learning basic content knowledge and skills first, prior to engaging in the practices of a discipline. We argue that the two are related dialectically, not sequentially or hierarchically.

A major design challenge for learning environments is to design for epistemic games in ways that embody the dialectical nature of learning. Indeed, many of the interactive and digital media learning designs reported upon in this issue share the epistemological commitment foregrounded in this article. A second major challenge is to prevent “backsliding,” where these artifacts and the associated game play simply become routinized and lose their game-ness and creativity. In other words, design efforts cannot be devoid from transforming learning cultures to support epistemic games.

These designs need to be situated within the creation of a supportive classroom culture and a culture of learning among teachers so as to not only minimize chances of backsliding but also increase the likelihood of sustaining innovation (Bielaczyc, 2006).

Figure 4. One group’s representations and methods.
Indeed, creating such cultures among both students and teachers is consistent with moving toward 21st century learning and teaching. This article is meant to contribute to dialogue on effecting such change.

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