van Aalst, J. (2012). Knowledge building and conceptual change: An epistemological resources perspective. In C. B. Lee & D. Jonassen (Eds.), Fostering conceptual change with technology: Asian perspectives (pp. 173-198). Singapore: Cengage Learning.

Knowledge Building and Conceptual Change: An Epistemological Resources Perspective

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Abstract

This chapter considers conceptual change theory in the context of knowledge building, an educational approach that emphasizes collaborative inquiry and idea improvement within a community. It is proposed that the epistemological resources perspective developed by David Hammer and colleagues provides a framework for analysis of conceptual change in a knowledge-building community. A case study involving 27 fifth- and sixth-grade students is then presented to demonstrate how this perspective can be applied to knowledge building, focusing on the nature and use of questions, prior knowledge, theories, and information. The implications for knowledge-building research and pedagogical design in the East-Asian context are also discussed.

Key words: epistemological resources; knowledge building; Knowledge Forum; conceptual change; science education.

Introduction

The debates surrounding misconceptions and conceptual change in science education can be characterized by two main theoretical positions. The position most subscribed to asserts that misconceptions are mistaken ideas that interfere with learning, and hence must be replaced or relinquished. For example, in a review of the literature in this arena, Mestre (1991) commented, “Because students have spent considerable mental effort constructing their ‘theories’, and because these theories do explain and predict some subset of physical phenomena, students do not *relinquish* their misconceptions easily” (p. 57, emphasis added). This literature examines why misconceptions are so difficult to eradicate, and claims that students’ ideas have a high degree of organization and form frameworks (Carey, 1988; Driver & Easley, 1978; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, Vamvakoussi, & Skopeliti, 2008). Chi’s research (1992, 2008) also focuses on the organization of concepts, particularly the role of ontological category mistakes. All of this work is underpinned by T.S. Kuhn’s historical analysis of science, particularly his notions of normal and revolutionary science, paradigm shift, and the incommensurability of paradigms (Kuhn, 1962/1996).

The second position argues that the replacement thesis is incompatible with constructivism (Smith III, diSessa, & Roschelle, 1993) and that recourse to the framework thesis is unnecessary to explain the available evidence (diSessa, 1993, 2002; diSessa & Sherin, 1998). Authors taking this position suggest that concepts are complex systems involving elements that can be considered *epistemological resources* for elaborating more comprehensive and coherent knowledge (Brown & Hammer, 2008; diSessa & Minstrell, 1998; Hammer, 2000; Hammer & Elby, 2003).

The epistemological resources perspective seems particularly suitable for thinking about conceptual change in the context of *knowledge building*, an educational model in which ideas are treated as improvable objects, similarly to the way in which real objects such as bicycles and telephones are improvable (Bereiter & Scardamalia, 2003; Scardamalia, 2002; Scardamalia & Bereiter, 2006). According to knowledge-building theory, students participate in a primarily 'design-mode' discourse in which they contribute ideas to a shared space, question the usefulness of those ideas and how to improve them, test and modify them, and gradually end up with a more useful knowledge system (Bereiter & Scardamalia, 2003). The goal of knowledge building is not so much to arrive at a predetermined and fixed endpoint—e.g., a shift from a naïve understanding of force to a Newtonian one—as to advance from the point at which students, as a community, began. Such advances are typically evaluated (informally) in terms of their usefulness in thinking about important problems and in terms of increases in 'explanatory power' and 'explanatory coherence' (Thagard, 1992).

The cognitive dynamics of knowledge building differ dramatically from those in other examples of conceptual change teaching, wherein the teacher assesses the gap between students' knowledge and some desired end point and employs teaching strategies designed to close that gap. Knowledge building relies more on *emergent* phenomena. In the context of addressing important problems of understanding, a community of students assesses the adequacy of its current knowledge, and lines of inquiry emerge, some of which lead to knowledge advances. This process is cognitively similar to the way in which scientific discoveries are made, except that students require much more guidance than scientists (White & Fredericksen, 1998). An essential aspect of learning how to build knowledge is the development and maintenance of a variety of cognitive abilities and social norms, including the ability to formulate ideas, coordinate theory and evidence, and talk together in ways that are appropriate to a given discipline. Reliance on emergent phenomena renders knowledge building inherently constructivist in nature and makes it a good candidate for exploring the epistemological resources perspective and accompanying complex systems view.

Few studies in the knowledge-building literature examine conceptual change beyond pre- and post-test comparisons, and the goal of this chapter is thus to explore the implications of knowledge building for research on conceptual change. The next section reviews the theoretical positions on conceptual change briefly described above, followed by presentation of a case study involving the use of an early version of Knowledge Forum® by a class of Grade 5/6 Canadian students to discuss how heat affects matter, and then a discussion of how epistemological resources were employed in this case. Finally, the main phenomena revealed in the case study are discussed from an East-Asian perspective. The goal of this discussion is not to generalize from Canadian students to Asian ones, but rather to consider the importance of these phenomena when considering the promise of knowledge building for fostering conceptual change in East-Asian contexts. As elaborated upon later in the chapter, the concerns about educational approaches are similar in both contexts, although their cultural underpinnings differ.

Examining Conceptual Change Theory

Kuhn's Theory

Many theories that employ the framework position draw from the analysis of T.S. Kuhn in *The Structure of Scientific Revolutions* (1962/1996) and *The Essential Tension* (1977). For example, Carey (1988) points out: "Although Kuhn's [1997] arguments are directed toward conceptual change in history, I believe they apply equally to conceptual change in children" (p. 126). The well-known conceptual change theory posited by Strike and Posner (1992) also developed an analogy to Kuhn's paradigm shift, although their theory was not concerned with learning, but rather with the question, "What does it take for people to change their commitment from one conceptual framework to another?" This theory is not empirically grounded in misconceptions research, but can be applied to explain it (Strike & Posner, 1992). Both Chi (1992) and Carey (1988) refer to "radical conceptual change" as an analogy to paradigm shift. The central claims of Kuhn's theory, as well as criticisms of it by philosophers of science, are discussed briefly in the following paragraphs.

Kuhn (1962/1996) was interested in how scientific communities make conceptual progress. He distinguished 'normal science', in which scientists solve puzzles within existing theoretical frameworks, from 'scientific revolutions', arguing that a scientific revolution involves a transition to a new paradigm, that is, a new grand theory or worldview in which the field needs to be recreated from new fundamentals. He assumed that the new paradigm was 'incommensurable' with the old (Kuhn, 1962/1996). Kuhn further pointed out that scientific revolutions have occurred relatively frequently throughout history, and he discussed numerous examples—some large, others small. He also claimed that science does not *begin* in a paradigm and discussed the transition from pre-paradigm science to the first paradigm at length. By analogy, if students' knowledge after teaching is paradigmatic, then researchers adopting the first of the foregoing positions (Vosniadou et al.) would argue that conceptual change involves a shift from the student' naïve framework to a more developed one, whereas those adopting the second position (DiSessa et al.) would argue that it is similar to the transition from pre-paradigm science to the first paradigm.

Philosophers of science have debated Kuhn's theory extensively, particularly its incommensurability thesis and the holistic acceptance of a new paradigm during a paradigm shift. For example, Dutch (1982) proposed a metaphor of a ball with a hard inner core of theories that have no competitors, have a solid observation base, and set standards for inquiry; a soft outer core with frontier theories that have few competitors, a good database, and few unexplained elements; and fringe theories that move in and out of the outer boundary. Scientists have also noted that they do not revise their theoretical commitments to the extent that Kuhn suggested; instead, commitment shifts occur because new scientists are trained according to the new paradigm, and the older scientists who adhere to the old paradigm eventually die (Reeves, 2008). Kuhn acknowledged this in his postscript to the second edition (1970). However, Kuhn was less concerned with conceptual change within *individual scientists* than with the advancement of *scientific communities*; if his theory is employed as a model for thinking about conceptual change in education, then it seems an overextension to apply it to individual students.

Epistemological Resources Perspective

diSessa (2002) criticizes research that views misconceptions as mistaken ideas to be replaced as "undervaluing students' naïve knowledge" (p. 47). The replacement view does seem educationally problematic because it invalidates the ideas students bring to the classroom. Indeed, it has been noted that what makes replacement difficult is that these ideas make sense to students; they serve them well, except in the science classroom. Further, the replacement view provides no explanation of how misconceptions can be productive resources for learning (Smith III et al., 1993) or for uncovering an underlying mechanism (Hammer, 2000).

diSessa and his colleagues, via a series of detailed studies of how students reason about physics concepts, have developed a perspective that considers students' intuitive ideas as *epistemological resources* for learning, resources that are useful as starting points for the development of more coherent knowledge (Brown & Hammer, 2008; diSessa, 1993; diSessa & Minstrell, 1998; Hammer, 2000; Hammer & Elby, 2003). Central to this work is the idea that concepts provide too course a grain size for analysis. The aforementioned starting points have been described in several ways. For example, Minstrell (1992) refers to *facets*, elements of student thinking that can be used to develop more coherent knowledge, whereas Hammer and Elby (2003) refer to *raw intuitions*. The main point for both is that these elements do not interfere with learning, but are productive resources for it. diSessa (1993) adopts a description closer to folk physics—*phenomenological primitives* (p-prims)—which describe features of knowledge that are general and widely applied. They are primitive in that they require no explanation—they are obvious to everyone. Some examples are the *force implies motion* p-prim (an effect requires effort) and *Ohm's law* p-prim (effort is resisted). P-prims are loosely organized and do not form networks with strong ties; thus, diSessa's (2002) perspective is called "knowledge in pieces." P-prims also have no covering theory that explains them, and hence cannot provide the level of accountability required for physics (diSessa, 2002).

diSessa and Sherin (1998) claim that what is required are concept models that can account for the variety of *kinds* of concepts and used to test empirically how concepts develop in students' reasoning. Thus, whereas concepts are usually regarded as categories and typicality is used to classify observations (e.g., a penguin is less typical of the concept 'bird' than a swallow), these authors introduce the *coordination class* as a kind of concept. Coordination classes are "systemtically connected ways of getting information from the world" and involve readout strategies and causal nets (diSessa & Sherin, 1998, p. 1171). For example, the concept 'acceleration' is not categorical, but primarily concerns the *extent* of an object's acceleration and is causally linked to force and mass; all three of these concepts are coordination classes, and they constitute a (partial) causal net. Although this example is taken from physical science, the notion of coordination class is not limited to this discipline, but also applies to psychological concepts such as motivation, intentionality, and agency. According to diSessa and Sherin (1998), 'coordination' occurs both within (e.g., coordination of force and acceleration in a particular situation) and across situations.

In sum, rather than assuming that students' ideas form coherent and stable frameworks that make conceptual change difficult, diSessa and his colleagues argue that the evidence for such frameworks is inadequate; they call for a set of referents that would render conceptual change theory more suitable as the basis for empirically testing hypotheses of how conceptual change occurs. diSessa (2002) and Brown and Hammer (2008) propose that concepts should be considered as complex systems with a large ensemble of constituents, including p-prims and coordination classes

Case Study: How Heat Affects Matter

To provide an empirical context in which to explore the epistemological resources perspective, an extended inquiry into how heat affects solids, liquids, and gases by Grade 5/6 students attending a Canadian elementary school is described in the following sections. The classroom work occurred in 1994 and 1995 and utilized a Computer-Supported Intentional Learning Environment (CSILE; for the orginal study, see van Aalst [1999, Chapter 4]). This database of student work was selected because the teacher involved was experienced in facilitating knowledge building and understood the principal features of a pedagogical design for knowledge building, including the creation of a classroom ethos in which it is safe to contribute ideas to a public discourse, a focus on understanding the core features of a domain, and the importance of explanation-oriented discourse (for analyses of some of this teacher's other databases, see Hakkarainen [2003] and Hewitt [2002]). It was thus the most promising database available for studying conceptual change in science education. The work of 27 students in the teacher's Grade 5/6 class in 1994/95 is here re-analyzed, aligning the analysis with current analytical and theoretical perspectives.

Pedagogical Design

In the first two weeks of the unit, students divided themselves into small groups and worked on investigative activities from a science kit; for example, they examined thermal expansion using a ring and a ball and examined heat conduction in various materials. They were then asked to discuss a three-part question on CSILE: *Hoes does heat affect solids/liquids/gases?* Students added their own theories to these discussions, but they also created new discussions on their own initiative; they improved their theories through discussion and research. After approximately seven weeks, the teacher initiated four new discussions. Three of these asked what the class had learned about solids, liquids, and gases; the fourth asked what *general principles* the class had learned about how heat affects matter. The students worked on these questions for approximately three weeks.

This pedagogical design offered excellent balance among the empirical exploration of thermal phenomena, the sharing and improvement of ideas, and synthesis of what the class had learned as a whole. Of particular interest was that students were asked both to discuss heat phenomena across apparently different domains—solids, liquids, and gases—and to formulate general principles that integrated these domains.

Classification of Students' Achievement

van Aalst (1999) divided the database into thirds based on the time a note was last revised, and then employed all of the writing by a given student in the last two-thirds to classify students' achievement into two levels of knowledge quality—low and high. His rationale for this analysis was that if a teacher examines a substantial amount of writing by the same student, then he or she can observe coherence among that student's statements and become more confident in his or her evaluation of the student's knowledge. For example, if a student uses the concept 'kinetic energy' correctly in the context of the expansion of a metal bar subject to heating that invokes a kinetic model of heat, then is there evidence of the use of other implications of the model, such as a correct explanation of thermal convection? van Aalst judged a student's writing as being of 'high' knowledge quality if it provided *one* explanation that invoked a scientific model—molecular or macroscopic—with a sufficient amount of surrounding textual material to indicate that the student understood the model (e.g., an elaboration or example), but *without* compelling evidence of misconceptions. An explanation that provided a scientific fact, but no surrounding textual material, was not deemed sufficient, and, conversely, nor was a single example with evidence to suggest an animistic or materialistic interpretation of heat sufficient to judge a portfolio as 'low' in quality. He found 14 students to have low knowledge quality during this period and 13 to have high (inter-rater reliability of 0.78 based on Cohen's kappa); see van Aalst (1999, pp. 79-80) for an example. Further, although students with high knowledge quality wrote more notes than those with low knowledge quality, there was no clear evidence on other measures of literacy, such as Canadian

Tests of Basic Skills (CTBS) vocabulary and reading comprehension test scores or the Flesch-Kincaid reading level of their writing.

These results suggest that approximately half of the students wrote theories that, on balance, suggested a conceptual understanding that would be acceptable at any grade level in K-12 education. However, the results do not mean that students' understanding resulted from their online writing. A few students had *prior knowledge* at this level of understanding, and some also identified out-of-school experiences as their sources of learning about heat and matter.

Rating of Individual Computer Notes

Turning to the new analysis presented in this chapter, all 595 of the computer notes leading up to the synthesis notes were rated. First, the students' own classification of notes using scaffolds were employed to identify a note as a *theory*, *new information/comment*, or *question*. In CSILE, students were required to declare one of these scaffolds when creating a note. Separate scales were then employed to rate the quality of the notes. Inter-rater reliability for coding using the following scales was 0.66 (Cohen's kappa, based on 50% of the notes).

For notes with *theories*, a scale developed by Galili and Hazan (2000) and used in several recent knowledge-building studies (van Aalst & Truong, 2011; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007) was employed. It is an ordinal scale with four levels: pre-scientific, hybrid, basically scientific, and scientific. Pre-scientific notes lack clearly identifiable elements that could be the basis of idea improvement; hybrid notes reveal some elements of scientific explanations that could be the basis of idea improvement; basically scientific explanations are correct explanations that typically lack insight into qualifying conditions (e.g., increasing the number of particles per unit volume is not the only way to increase density), and scientific notes would be completely correct explanations at any K-12 level.

For notes that presented *new information/comment*, Hakkarainen, Lipponen, and Järvelä's (2002) scale focusing on the use of information was adapted (simplified). This scale does not take content correctness into account, but suggests different epistemic stances toward information. For example, if students are realists, then they may think that new information requires no interpretation, but "speaks for itself." If they do more work using the information, for example, if they use it as evidence to make a point, then they may hold a more sophisticated stance. The modified scale used in this analysis had four levels: isolated facts, collection of facts, partly integrated explanation, and integrated explanation.

Finally, for notes that posed *questions*, van Aalst's (1999) original scale, which has three levels—general questions, fact-seeking questions, and questions that could be posed as hypotheses—was employed. Many of the general questions in the students' notes were explanation-seeking questions, but determining that this was the case required further elaboration. For example, "Why does heat flow from hot to cold places?" could be asking about an underlying mechanism, but it could also be probing more deeply into the reasons for that underlying mechanism.

The results of this analysis are shown in Figure 1. To generate this figure, the computer notes were divided into two phases of equal duration—orientation and inquiry; for each scale, the results for the orientation phase are shown in the upper row and those for the inquiry phase in the lower row. Observe that the bars do not show data from individual students, but rather the totals from all students at a specific knowledge level (high or low). The four following important patterns can be discerned.

1. Questions: The students with high-quality knowledge wrote more questions of all types than other students; the difference was greatest for *hypotheses*. The epistemological resources perspective views all questions as epistemological resources, but some are more useful than others for knowledge building. Fact-seeking questions often fail to lead to progressive discourse, and general questions require further elaboration before they can be understood, but hypotheses contrast (conceptual) possibilities and suggest what measures the community could undertake to improve its understanding.

2. Prior knowledge matters: Students who were deemed to have high-quality knowledge subsequently wrote more theories rated basically scientific or better during the orientation phase. This finding is unsurprising: students who understand more at the outset are more likely to share their knowledge and provide elaborations and examples. The implication is that prior knowledge can be an important epistemological resource.

3. Pre-scientific and hybrid notes during the orientation phase: Although the effect was smaller than that in (2), students with high-quality knowledge also subsequently wrote more notes that lacked conceptual content or contained misconceptions (pre-scientific and hybrid) during the inquiry phase relative to other students. *More than half of their notes fell into these categories.* This finding is more surprising, that is, that more knowledgeable students would be more willing to contribute ideas that were conceptually problematic in some respect. It may have particularly important implications in East-Asian contexts, where students are more eager to avoid losing face than their Western counterparts.

4. Balance of information and theory notes: As expected, during the orientation phase there were relatively few notes with new information and relatively few differences between students with high and low knowledge quality. Instead of looking for information, most students were generating theories about what they had observed during their hands-on experiences. In the inquiry phase, this pattern was reversed. Students introduced new information, although it led to relatively few theories. In this respect, their use of information as an epistemological resource was rather underdeveloped, a result also found in a recent study involving Grade 10 students (van Aalst, 2009). This finding suggests the presence of a *simple knowledge belief* (see Schraw, Bendixen, & Dunkle, 2002), according to which students locate information to answer their questions, but engage little in progressive discourse. However, students with high-quality knowledge did more work with information, and contributed more partially integrated descriptions.

[Insert Figure 1 about here.]

In summary, the foregoing analysis suggests several candidates for epistemological resources: *questions*, *prior knowledge*, *theories*, and *information*. Each of these could be further divided into subcategories. For example, prior knowledge includes valid assertions, raw intuitions that can be developed, and invalid statements (statements that are claimed to be logically true but can be shown to be false). The potential role of these resources in the development of understanding is explored further in the next section.

A Closer Look at a Discussion

This section explores the potential and actual use of epistemological resources in one of the discussions in the foregoing case study: a discussion of 11 notes examining whether gas is affected by gravity. This discussion was chosen for analysis because it involved the most articulate students in the class, who collaborated frequently, and because the topic is one that students generally find difficult, even toward the end of high school (diSessa & Minstrell, 1998). In the original study, it was regarded as one of the most advanced discussions in the database (van Aalst, 1999, Chapter 4). The discussion was started by Jerry on December 13, 1994, and the last note revision was made on January 27, 1995 (pseudonyms are used throughout this analysis); it involves notes rated as hybrid, basically scientific, and scientific in the foregoing analysis, and two students with low achievement and six with high.

The analysis in the previous section made use of the requirement for students to declare a scaffold ('thinking type' in CSILE) with each note; thus, a note may have been analyzed as a theory note even if it also contained a question as part of the theory description. However, the present analysis requires a smaller grain size to provide greater detail about the student interactions in the discussion and the emergence of understanding. Therefore, in the transcript shown in Figure 2, the text of each note is divided into separate statements, making it possible to focus attention separately on the questions, scientifically acceptable statements, and statements suggesting a more limited understanding within each note. Figure 3 was then constructed from the transcript to visualize the interactional details. For example, Derrik starts note 9 with the claim "I think that gas is affected by gravity," which echoes Jerry's statement in note 7 and Andrew's in note 6. Derrik could have made this claim without any precedent, or his claim could have been prompted by Jerry or Andrew's note. For simplicity, and because some research shows that students are more likely to read and respond to the most recent notes (Hewitt, 2003), only the relation to Jerry's note is shown in the figure. Thus, the arrow from the first statement in note 9 to the first statement in note 7 signifies that the former could be a response to the latter. In this example, the line is solid to indicate that both authors are making similar claims; by contrast, the dashed line between the first statement in note 10 and the first in note 9 indicates that the authors take different positions on the same issue. Figure 3 thus shows considerable detail about the interactions that took place during this discussion.

[Insert Figures 2 and 3 about here.]

The discussion involves 5 questions and 26 statements that propose or elaborate upon theories; it contains no statements referring to sources of information. The questions are of a high level: the two in note 3 seek explanations, and the final two in the discussion (statements 8.1 and 11.1) propose hypotheses. The two questions embedded within the theory notes (statements 1.2 and 6.2) can be considered metacognitive: e.g., “Why shouldn’t it be?” (1.2) suggests that Sean is confident in his previous claim that gas is affected by gravity. The two explanation-seeking questions are not directly related to the main problem, and are not pursued. The two hypotheses are not pursued either, although pursuit of the first is not necessary, as Matt has already offered an explanation to the puzzle in note 5. Overall, the questions show little evidence of operating as epistemological resources during this discussion. However, the discussion as a whole is a response to an explanation-seeking question.

Throughout most of the discussion, the students open their notes by claiming that *gas is affected by gravity* (statements 1.1, 4.1, 5.1, 6.1, 7.1, and 9.1) and that *gas is a form of matter* (2.1, 5.2, 7.2, and implied in 9.1). These claims appear to arise from prior knowledge, and are restated by students when they begin their notes to establish common ground—about this much there is agreement. Near the end of the discussion, Emma suggests that *not all* gases are affected by gravity, pointing out that helium behaves very differently from carbon dioxide (10.1 and 10.2). Although her note is incorrect in asserting that carbon dioxide is unaffected by gravity, it helps to clarify the need for a more detailed understanding of gravity’s effect on gases. Her contribution is an epistemological resource for coordinating understanding of how gravity affects gases of different kinds. Further, the example of helium rising seems so familiar that no one disputes it: this prior knowledge seems to function as an epistemological resource for grounding the new, qualified, claim that "it depends." In the final note, Matt raises a new question: "I need to understand what would happen if different gases had different weight. Would the effect of gravity be stronger? Weaker?" His expression lacks precision—he means to say "density" rather than "weight"—but the question is related to Matt's overall approach to his work in the database. He is particularly interested in density as an explanation for the variations in behavior of different substances in the same phase (van Aalst, 1999, Chapter 4).

Although some of the students refer to gases having "no weight" and others to them having "small weight," the early notes consistently claim that its weight is too little to keep a gas from rising (statements 1.3, 2.2/2.3, and 4.2/4.3). This observation is a *puzzle* in Kuhn's terms: other substances (e.g., solids, raindrops) fall to the ground, but gases do not seem to. Then, in the last part of note 5, Matt offers a partly worked out solution to the puzzle: "I think that gas is affected, and therefore does not rush up into space that fast. I think that if it was not affected, the gas would zoom very fast straight into the sky, because it would be free to travel wherever it wanted." Of course, Matt is referring to the existence of the atmosphere as evidence that gases do not simply rush into space, and are therefore affected by gravity. As with the helium example mentioned earlier, the students understand his insight, and two of them help to clarify his explanation. Andrew—a student with low achievement—first states that "if it [gas] was not affected by gravity there would be no life on earth because all the air would rush to space" (6.3), and Derrik restates the explanation one more time, replacing "air" with "oxygen" (9.3). The development of this explanation involves a creative act that relies on prior knowledge (Matt needed to search for an explanation that would be compelling, and found one), followed by idea improvement, which also relies on prior knowledge.

Concurrent with these developments, Jerry attempted a different tack on the puzzle. In note 7, he clearly asserts that gases are affected by gravity as a logical consequence of the assumption that all matter is affected by gravity. Then, in note 8, he proposes a rough idea for an experiment to measure the weight of the gas contained in a box. His idea is ingenious, although not fully developed and difficult to carry out: a 5-liter box of air would give a reading of only 6.5 grams, and students would have to consider how to contain the air. The experiment could be carried out with a vacuum pump, but elementary school students (or their teacher) would be unlikely to have sufficient experience with such a device to think of this option. Fortunately, Matt's suggestion (note 5) does not require such a difficult experiment. Daily life provides sufficient evidence that gases are affected by gravity, he asserts.

In sum, it seems that these students accomplished a great deal in their discussion. They came to the discussion with the belief that gases are affected by gravity, suggesting a correct ontological understanding that gas is a form of matter, and that matter is an entity that has the property of being affected by gravity. The discussion thus dealt with a puzzle concerning their observations about the size of gravity's effect on gases. This puzzle involved weight as a coordination class, and the students needed to coordinate their observations about the extent of gravity's effects across different gases and across different forms of matter. The discussion ended with a more specific question than the one the students had started out with and one that could be studied further. However, the specific way in which the students improved their collective understanding of gravity and the behavior of gases could not have been predicted by the teacher, and it is unlikely that the students were fully aware of what they had accomplished. In the East-Asian context, it would be important that students' discourse results in clearly identifiable outcomes.

The students in this analysis also failed to develop a coherent conceptual framework. Their concepts remained too undifferentiated to be able to develop a coherent such framework. For example, their use of 'weight' remained vague, and they never talked about gravity as a force or distinguished among 'weight', 'mass', and 'density'. However, some of the more articulate students did pursue a concept consistently throughout their online discussions, thereby improving that concept and gaining a better understanding of its usefulness. The original study (van Aalst, 1999) included several case studies describing how individual students approached their work in CSILE, including one showing that Matt consistently pursued the concept of density. Although his early writing revealed a limited understanding of density as the number of particles per unit volume, his case study showed that over time he came to realize that the weight (mass) of the particles could also affect density.

The Role of Epistemological Resources

A single case study does not permit generalization about the causal mechanisms involved in conceptual change, but its findings can nevertheless be used to formulate a set of hypotheses and outline a research agenda. This section discusses the epistemological resources revealed in the study—questions, prior knowledge, theories, new information, and puzzles—and the next section puts this discussion into the East-Asian educational context.

Questions

Questions are generally regarded as a driving force in inquiry-based learning. Project-based learning, for example, employs the notion of a 'driving question'

(Krajcik & Blumenfeld, 2006). A driving question is an example of an epistemological resource. In the case study discussed in the previous section, the questions that led to the various discussion notes can be considered driving questions. Quantitative analysis shows that the students who attained a high quality of knowledge posted more questions of all types, especially questions that can be cast as hypotheses. However, the one discussion examined in detail here suggests that questions do not necessarily function as epistemological resources, perhaps because this discussion lacked dialogue and was relatively short.

It would be useful to examine whether it is important for eventual knowledge quality that questions be answered; it is possible that simply formulating a clear question requires a clarity of thought that makes a direct contribution to knowledge quality. In the West, students are often disappointed if the questions they post online are not answered, and in East-Asian contexts question-answer sequences are a very common mode of interaction. In knowledge building, however, it is less important that the majority of questions are answered than it is that some questions are productive and lead to sustained inquiry and discourse.

Prior Knowledge

Prior knowledge is the foundation upon which students build knowledge. The present study suggests that prior knowledge functions as an epistemological resource in several ways.

First, prior knowledge is a *source of ideas*. In the original study, van Aalst (1999) found that students made little progress on topics for which they lacked background knowledge: for example, they were interested in understanding the nature of fire, but lacked the knowledge that would have enabled them to think of it in terms of combustion and chemical change. In a study of Grade 10 and 11 students, van Aalst

(2009) found that when students were trying to understand aspects of a SARS outbreak and the media's handling of it, they made greater progress in understanding how infection occurs, drawing on knowledge from their science courses, than in understanding the media's handling of the outbreak. Thus, building new knowledge requires substantial knowledge, and knowlede building may therefore not be a suitable approach in areas in which students have little prior knowedge. Even if teachers do not provide the driving questions, and these questions instead emerge from the discourse, they may still have a role to play in helping students to evaluate the promise of these questions for inquiry.

Second, the availability of *widely shared* knowledge is also important. This kind of prior knowledge enables students to make some claims that do not require justification, as they are familiar to everyone. In the present study, for example, Matt claimed that air does not rush into space and Emma that a helium balloon rises when released. Students are likely to have learned these things from everyday life, including breathing and watching television. Without the common ground provided by this kind of knowledge, no knowledge-building discourse is possible. Indeed, one difference between students and scientists is that the latter have much more deeply grounded knowledge. In the development of the "old quantum physics" at the beginning of the 20th century, the basic tenets of the classical physics of planetary motion and the methods of calculus were not in question; only the *ad hoc* assumption that energy is quantized was added. The novelty of the old quantum theory lay not in the calculations, which almost any physicist of the day could have completed (Born, 1960), but in the idea to quantize energy. Similarly, Matt and Emma used observations that would have been familiar to any member of their class to help to advance understanding. Hence, the significance lay not in the observations themselves, but in the insight to introduce them in this situation. The teacher clearly could not have predicted that knowledge of breathing or helium balloons would turn out to be important to the discussion.

Third, the finding that the students who had attained high-quality knowledge (and generally began with more extensive prior knowledge) wrote more early notes revealing *misconceptions* is very important from the epistemological resources perspective. In the original study, it was found that these students actually wrote approximately twice as many notes in total as other students. Further research is needed to determine students' motivation for writing notes containing misconceptions and whether there is any effect on knowledge quality when more students write such notes. One explanation for why the students with high-quality knowledge wrote notes with misconceptions is that they could *afford* to do so, as their other notes and social position compenstated for those with misconceptions, and hence they lost no face by writing them. It is possible that students who end up with high-quality knowledge are in a psychologically safer position to take risks than other students. Teachers need to invest considerable effort in overcoming such an effect to create a learning environment in which it is safe for all students to become risk-takers and in which ideas are considered on the basis of merit rather than authorship (Lee, Chan, & van Aalst, 2006; van Aalst & Chan, in press).

Fourth, as suggested earlier, although the students in the case study wrote many notes that introduced new information, the quantitative results suggest that new information and theory development are rather separate activities. The students tended to generate theories first and then locate information. However, the new information that was obtained did not generally seem to have led to new theories and quesitons. As the author has suggested elsewhere, this finding may reflect an inadequate epistemological understanding of information (van Aalst, 2009; van Aalst, Fung, Li, & Wong, 2007). Although the role of information use has received relatively little attention in the knowledge-building literature, it is clearly an important epistemological resource, the use of which should be further developed.

Puzzles

It is proposed that the discussion presented here involved *puzzle solving* rather than the radical conceptual change associated with scientific revolutions. The students were in general agreement with the categorical aspects of the conceptual domain; that is, they seemed to believe that matter has the property of being affected by gravity and that gas is a form of matter and therefore also affected by gravity. There was little evidence of any ontological disagreement about the nature of gases. However, the students were puzzled by their observations about gases because gravity's effects were not as noticeable for gases as for other forms of matter. The discussion can be seen as an attempt to gain an understanding of 'weight' as a coordination class: a concept they could use to measure the extent of gravity's influence on matter and to coordinate observations involving gases of different kinds (e.g., air and helium) and across different substances. The students managed to solve the puzzle in part, although it would be possible to articulate the associated causal net more fully. In knowledge building, students are not generally reconstructing a conceptual domain from new fundamentals, as in revolutionary science (Kuhn, 1970), but are solving puzzles. In the present example, the puzzle may have resulted from a partially articulated conceptual framework; students may have believed that matter is affected by gravity without having an appreciation of the casual net associated with this effect.

Implications for Learners in East-Asian Contexts

The foregoing case study involved Canadian students, but the author contends that the phenomena therein revealed also have significance for East-Asian learning contexts. For example, Western students' hesitation about sharing ideas when they are unsure of the validity of those ideas is likely to be an important constraint in implementing knowledge building in other cultural contexts too. And any causal relation between working on such ideas and conceptual change is *cognitive* rather than culturally mediated, although the *willingness* to utilize the causal mechanism in learning practices can be expected to be so mediated. Therefore, it seems worthwhile to examine these phenomena from the perspective of East-Asian learning environments; although it is impossible to make empirical generalizations, such an examination can help to set a research agenda.

Features of Educational Contexts in East Asia

Traditionally, East-Asian societies have been strongly influenced by the teachings of Confucius. In China, the civil service examinations inspired by these teachings were used almost continuously from the Han Dynasty (206 BC–220 AD) until the end of the imperial era to select men from all walks of life for government positions (Bol, 2008; Elman, 2000). Preparing for these examinations involved years of effort and commitment, but passing them led to upward social mobility and was a matter of great pride and advantage for the families of those who succeeded in doing so. As an ancient Chinese idiom states, "Although studying anonymously for 10 years, once you are successful, you will be well-known in the world." For a variety of reasons, including the influence of the West and the increasing difficulty the examination system had in selecting the best candidates for government positions (Elman, 2000), the influence of Confucianism declined steadily throughout the 19th and 20th centuries. In the past decade, Western and constructivist educational perspectives have begun to shape educational policies throughout East Asia. Curriculum reform in this period has emphasized learning how to learn, inquiry, critical thinking, and school-based assessment (CDC, 2000; CDC/HKEAA, 2007). However, despite the many changes that have taken place, a number of traditional values grounded in Confucianism continue to determine attitudes toward education across the region. Three of these values are described in the following paragraphs.

Filial Piety: Respect for One's Family and Ancestors. East Asians hope to bring honor and prosperity to their families, and entire families support specific members in their studies. It is widely regarded to be children's duty to prepare themselves for examinations. This kind of respect often leads to hierarchical social systems in which people defer to the authority of those in higher strata. In classrooms, this means that students are often reluctant to question the authority of the teacher and tend to rely on instructions from the teacher rather than on their own initiative.

Achievement Orientation. The region's schools continue to be examination-oriented at all levels of formal education. East Asians are inclined to consider *effort* more important to success than ability, which is seen as a result of effort, whereas Western students tend to attribute success and failure more to innate ability. In East-Asian countries, the effort necessary to succeed in examinations is considered to be a force for moral self-improvement (Li, 2009). This achievement orientation produces competitive learning environments. For example, elementary school students compete for places at secondary schools that have a good success rate in government examinations. In Hong Kong secondary schools, teachers may schedule remedial lessons during holiday periods and reserve several months of instructional time to prepare students for government examnations (also see Gao & Watkins, 2002). Although many Western countries also make use of government examinations, East-

Asian examinations tend to be particularly difficult and comprehensive in their coverage of the curriculum. Of the 29,713 students who took the Hong Kong graduation examination in physics in 2008, only 4.6% received an ‘A’; 30.4% received a grade anywhere from ‘A’ to ‘C’, and in total only 77.6% received a passing grade (Hong Kong Examination and Assessment Authority, 2008). In the Netherlands, at the highest level of secondary education, examinations tend to be less directly based on the syllabus; rather, students are expected to be prepared to reason about unfamiliar problems that require physics knowledge. However, despite the emphasis on practice, students from East-Asian countries outperform their counterparts from most Western countries on international comparisons such as the Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA)—an effect known as “the paradox of the Chinese learner” (Watkins & Biggs, 1996).

Avoidance of ‘Losing Face’. An important social skill in East-Asian societies is to avoid putting others in embarrassing situations in which they could lose face. As a result, students are often reluctant to share ideas that they believe to be partly incorrect, thereby revealing their own lack of knowledge, or to critique the ideas of others—including those of the teacher. Being seen to be incorrect by peers and the teacher contributes to low self-esteem. Li (2009) points out that Chinese students prefer to commit new information to memory and understand it *before* they raise questions about it or discuss it with others. Most teachers in Hong Kong who have attempted knowledge building believe that their students need considerable time to learn how to engage in idea-focused discussions (Lee et al., 2006). Nevertheless, after such preparation, Hong Kong students have proved very willing to contribute to discussion forums (Chan, 2009).

These three concepts simplify the East-Asian context, but together they suggest why the region's classrooms generally have a great deal of structure. The teacher is viewed as an authority figure, provides a great deal of direct instruction, and sets tasks for the students. When students engage in discussions, the teacher provides them with a summary or model answers. Students cooperate with the teacher and attempt to learn the subject matter to the expected standards, but are reluctant to engage in activities that do not lead to outcomes that are clearly relevant to the examination syllabus. For example, in a comparative study of ninth-grade Australian and Taiwanese students who participated in collaborative and activity-based instruction, Wallace and Chou (2001) found the interactions among the Australian students to be more focused on enhancing social relationships, whereas the Taiwanese students were more focused on the learning task. In the East-Asian context, poor academic results often motivate students to try harder, as they are not attributed to a lack of ability. Ability is considered an outcome of education, not a constraint to it. Parents in all social strata place great importance on their children's education and support their teachers, for example, by monitoring children to ensure their homework is completed. The high standard of the examinations, as well as their nature, aligns educational systems with a fixed end-point view of conceptual change—students are considered 'deficient' in knowledge, and the aim of educational activities is to remove those deficiencies. Although Western observers may criticize the region's learning environments for being teacher-centered, East-Asian teachers tend to disagree. For example, a Chinese teacher interviewed by Gao and Watkins (2002) stated, "If the teacher focuses on encouraging students, setting questions to challenge them, directing them to explore new knowledge, I don't think that means teacher-centered" (p. 73). Wu and Huang (2007) concluded that low-achieving ninth-grade students in an interactive environment in Taiwan "did not receive direct support from the teacher that could constantly draw their attention to the content, [and] had fewer opportunities to listen to or engage in thoughtful discussions about concepts" (p. 747).

As pointed out earlier, East-Asian education students perform very well on the TIMSS and PISA, but the region's governments recognize that enhancements are necessary to promote the development of 21st century skills (CDC, 2000; CDC/HKEAA, 2007; Chan, 2011). Among the new skills they hope to develop are self-reliance (i.e., agency) and confidence in learning, the ability to work with others, and the ability to deal with novel situations. Self-reliance in learning requires meta-cognition. Rather than the 'learned helplessness' that can result when students rely on teachers to tell them how they are doing and to design learning paths, students need to take greater charge of their own learning. Although these developments are also necessary in Western countries, East-Asian education systems provide a good vantage point from which to consider them due to their strong emphasis on achievement. However, it should be remembered that these learning outcomes are *fixed endpoints* that are not specified by the students.

Conclusion

The epistemological resources perspective and its concomitant assumptions about the role of misconceptions in conceptual change (Hammer, 2000; Hammer & Elby, 2003; Smith III et al., 1993) have been adopted in this chapter because they are philosophically more consistent with constructivism, which claims that students use prior knowledge to build new knowledge, than the view that misconceptions are to be replaced or relinquished. In the case study discussed herein, it was seen that prior knowledge functions as a source of ideas, and it was proposed that the presence of widely shared prior knowledge is an important epistemological resource for conceptual change. It was also found that students who end up with high knowledge quality are more willing to contribute ideas containing misconceptions than other students, a finding that reverberates with Kapur's (2008) finding that Asian students who first solve ill-structured problems in small groups later outperform other students in individual and well-structured problem-solving tasks. The epistemological resources perspective can also be useful in revealing resources that are not utilized sufficiently; for example, there was some evidence in the case study that once students began to introduce new information, theory development diminished.

In one sense, although the contribution of prior knowledge to conceptual change is well known, the *uncontested* ideas of individual students play a limited direct role in conceptual change within a community. These ideas may become diffused and widely shared, but this in itself is insufficient; students are simply 'catching up' with what other students already know, and the ideas of the community as a whole are not improved. However, these ideas can make an *indirect* contribution because they enhance the availability of shared and uncontested knowledge for puzzle solving. Although the community needs to become aware of its uncontested ideas, a more important locus of students' attention should be the ideas that require improvement. Of course, these ideas already receive a great deal of attention in all conceptual change teaching that involves the introduction of cognitive conflict, but, in these approaches, the nature of the cognitive conflict to be introduced and the instructional strategy designed to address it are in the teacher's control. In knowledge building, the cognitive conflicts occur in puzzles that emerge from the community's discourse. It is suggested that solving these puzzles is much more difficult than learning during traditional conceptual change learning because it is possible that *no one knows* the solution—that is, there is no endpoint in sight. Still, the students and teacher can make progress from where they started. In this more difficult work, collaboration and discussion are not merely pedagogical choices; they are necessary because they provide more powerful learning mechanisms. The solitary approaches that prevailed among Asian learners in the past (Li, 2009) are not equipped for the level of autonomous learning required for knowledge building.

The absence of a fixed endpoint that is known at the outset is highly controversial for Asian students and teachers; however, they can rest assured that such absence does not imply the absence of goals and standards by which to measure accomplishments.

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Note 1	1.1 I think that gas is affected by gravity,
Sean	1.2 why wouldn't it be?
High	[I think that gas just doesn't seem to be affected by gravity.]
	1.3 Because of its extremely light weight, I think that gravity would not be able to keep gas from rising.
	1.4 I think that when the gas comes in contact with heat the heat would make the gas even lighter and it would rise faster.
Note 2	2.1 I think that although gas is matter
Albert	2.2 it has no weight whatsoever.
Low	2.3 Since there is no weight, there is no way that gravity can pull gas to the ground.
	2.4 Some gases can be turned into liquid, gasoline is turned into liquid so it can be used to power a car, liquids can be turned into gas. Water, when exposed to heat, vaporizes.
Note 3	3.1 I need to understand why the matter of one substance can be changed into another type of
Albert	matter.
Low	3.2 I would also like to know why only some forms of matter can be changed and others can't.
Note 4	4.1 My theory is that gas is affected by gravity.
Julius	4.2 I think that gas has no weight
High	4.3 so you can't really see the effect.
Note 5	5.1 My theory is that gas is affected by gravity. I think that everything that has matter is
Matt	affected by gravity.
High	5.2 I think this because everything that has matter has weight. Even air has weight,
	[and that is why we can't just float in air forever.]
	5.3 I think that gas, being very light, would be very weakly affected by gravity.
	5.4 I think that gas is affected, and therefore does not rush up into space that fast. I think that if it was not affected, the gas would zoom very fast straight into the sky, because it would be free to travel wherever it wanted.
Note 6	6.1 I think that gas is affected by gravity.
Andrew	6.2 Why not?
Low	6.3 I think that if it was not affected by gravity there would be no life on earth because all the air would rush to space.

Note 7 Jerry High	7.1 I think that gas is affected by gravity 7.2 because gas is matter 7.3 and anything that is matter is affected by gravity.
Note 8 Jerry High	8.1 Does gas weigh anything? What would happen if you had put some sort of gas in a box and the box could contain it? What would be the effect? Would the gas weigh anything inside the box because the gas is contained?
Note 9 Derrik High	9.1 I think that gas is affected by gravity, everything is. 9.2 But since gas is so light gravity cannot keep it on the ground. 9.3 If gas wasn't affected by gravity, then all the oxygen that we need to survive would float out into space and we would die.
Note 10 Emma High	10.1 I think that some gases are affected by gravity and some aren't. 10.2 Good examples would be carbon dioxide, which has no gravity since it is almost like air, or helium which does the opposite, by rising higher instead of falling with gravity's pull.
Note 11 Matt High	11.1 I need to understand what would happen if different gases had different weight. Would the effect of gravity be stronger? Weaker?

Figure 2
Transcript of the "Is gas affected by gravity?" discussion