The Roles of Knowledge in Knowledge Creation

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Abstract Reading comprehension research of the 1970s established that prior world knowledge is a determiner of the acquisition of new knowledge, mainly by providing schemas into which new information may be entered. This should clearly apply to students creating knowledge by building on their existing knowledge and on knowledge gained from other sources. In addition, researchers on Knowledge Building have identified other kinds of knowledge useful in knowledge building, including knowledge of promisingness, knowledge about knowledge (epistemology), principled procedural knowledge, and knowledge about external expectations (such as curriculum standards and tests). This symposium brings together researchers who have studied various roles of knowledge in knowledge building, with the goal of at least organizing the distinct views but if possible producing an integrative framework for treating knowledge in creative work with ideas.

Introduction

The importance of prior world knowledge in knowledge acquisition was firmly established by research during the 1970s (Schallert, 1982) and was explained by a theory that posited cognitive structures (schemas) acquired through meaningful learning, which provide frameworks for entering new information and integrating it as knowledge (Rumelhart, 1980). Since that time a number of constructivist educational approaches have arisen that seek to go beyond knowledge acquisition to some more active and creative engagement of students with knowledge and ideas. With it have come suggestions that prior knowledge can inhibit creative work with knowledge and that a limited amount of prior knowledge may be optimal (Simonton, 1999, p. 120). The implication is that, beyond some essential knowledge to build on, the rest of creative knowledge work is pure process. A different view, however, is that domain knowledge plays an active and vital role in work with knowledge and ideas (Weisberg, 1999), but that additional kinds of declarative knowledge become important when the emphasis shifts from knowledge acquisition to knowledge creation. These include (1) epistemology (knowledge about knowledge); (2) knowledge about how knowledge is created (e.g., Li & Kettinger, 2006); (3) knowledge of misconceptions, pitfalls, and promising inquiry paths within a domain; and (4) domain-specific "principled practical knowledge" (Bereiter, 2014), of which the most fully developed example is TRIZ (Orloff, 2013), a set of heuristics for solving engineering design problems. Finally, in education contexts there is the knowledge that teachers need in order to build a community that has knowledge creation as its organizing center.

This symposium brings together researchers who have investigated the roles of different kinds of declarative knowledge in the context of Knowledge Building, an educational approach in which collaborative knowledge creation is the goal and principal activity (Scardamalia & Bereiter, 2014). The purpose of the symposium is to elaborate the accounts of different kinds of knowledge functioning in knowledge building/knowledge creation and to work toward a coherent framework within which to pursue further research and development related to this important but relatively undeveloped line of research within the constructivist conceptual space.

One way of interpreting the "wide lens" theme of CSCL 2019 is that it calls for taking fuller account of the processes of human learning that machine learning, even in its most advanced forms, still lacks. Complexity

scientist Melanie Mitchell has said the barrier AI has not yet surmounted is "meaning." The most serious failings she cites reflect inability of AI to understand what Karl Popper called the "problem situation," and which he saw as essential to the creation and assimilation of new knowledge. Achieving understanding of a problem situation, however, invariably requires more than the "embodied, enactive, extended, and embedded" processes that distinguish human learning. It requires substantive knowledge. Knowledge, in its many forms and contexts, has been a perennial subject of research in the learning sciences. This symposium, nevertheless, can be claimed to have a "lens-widening" effect with respect to its uses in knowledge creation itself and in constructivist educational approaches. It does this by identifying a variety of kinds of substantive knowledge that can actually be put to use in ways that augment the remaining advantages human learners have over machines.

Plan of the symposium

The plan of the symposium is to allocate four minutes to introductory comment and six minutes to each of six presentations. Following this will be a panel discussion, moderated by Marlene Scardamalia, in which authors of the six presentations will address possibilities of an ontology of types of knowledge involved in knowledge building/knowledge creation and ways of taking fuller advantage of them in education. The moderator will determine when to open the discussion to the audience but will allow a minimum of 8 minutes for it.

Building on collective prior knowledge for knowledge building across school years

Jianwei Zhang and Jiyeon Lee

Building on what the learner already knows is a broadly accepted and practiced principle of learning. While existing notions of prior knowledge focus on existing knowledge of individual learners brought to a new learning context; research on knowledge creation/knowledge building in schools needs to expand this concept to include *collective prior knowledge*: knowledge built and accumulated by the community through its prior inquiry practices that may be transferred to the current knowledge work. Collective prior knowledge is not as simple as the sum of what each individual member knows and remembers. Rather, it is an emergent and social entity that primarily exists in the community's social knowledge space as epistemic artifacts, discourse, and practices. In real-world knowledge-creating settings, members continually build on their team's prior work— such as conceptual insights already gained, designs and tools created/used before, and cases and problems encountered—to support their new creative endeavors, transcending boundaries of time, space, and tasks. Research on Knowledge Building and CSCL has produced a strong account of how students advance their collective knowledge through interactive discourse (Bereiter, 2002; Stahl, 2006), building on one another's ideas generated in the undergoing inquiry process. Extending such research, the notion of collective prior knowledge suggests a longer-term view of knowledge building and transfer: we need to investigate how students access and tap into their community's previous knowledge work across school years for sustained knowledge building in the related problem spaces and domain areas. Such long-term build-on is possible with the support of online platforms in which students' contributions and interactions are automatically archived. The challenges are to turn the detailed records of online interactions into an accessible/useable knowledge resource (Zhang, 2009), to enable cross-context fluidity, and to support students' reflective creative efforts to build idea connections in their individual work and collaborative discourse. Herein we report an exploratory study that investigated the designs and processes to address these challenges.

This design-based research was conducted among a group of elementary school students during three successive school years as they studied in Grade 4, 5 and 6. In their science curriculum, students studied three interrelated areas: light in Grade 4, climate and environment in Grade 5, and astronomy in Grade 6. The science inquiry each year was supported with Knowledge Forum. In addition to the regular Knowledge Forum views (workspaces) where students pursued knowledge building discourse, a "super view" was created in the database of Grade 5 and 6 in which students revisited the syntheses of ideas from their previous years and posted new syntheses of their current inquiry. The syntheses were composed using a set of scaffolds to document the journey of thinking in each problem area: *Our research topic and problem(s), We used to think… now we understand, and We need deeper research*. The synthetic knowledge artifacts were used as a boundary-crossing (Akkerman & Bakker, 2011) support to enable students' access and revisiting of their collective prior knowledge. Students individually read and built on the syntheses online, some of which were further discussed at whole class meetings as related to the current inquiry. Multiple sources of data--including online discourse

records, classroom videos, student interviews--were analyzed to examine the knowledge building interactions and idea build-on across school years, drawing a combination of qualitative and quantitative analyses.

Comprehensive data analysis is still underway. Preliminary findings identify several productive patterns by which students tapped into the ideas generated by their community in the previous school years to support their new inquiries. These included (a) carrying on prior concepts as the explicit focus of continued discussion, online and face-to-face, (b) reusing/embedding prior ideas (e.g. reflection of light) to support new inquiry and discourse to solve specific problems (e.g. how glacier melting affects climate change), and (c) reflecting on cross-domain connections to understand the whole picture and develop coherent understandings. As a student posted in the Grade 6 Super View when studying astronomy: "*A connection from grade 4 to grade 6 is that you need light to sustain a planet. If a planet has a source of light, it probably will have heat. Without light and heat, our planet would be cold and dark and we would all die. Luckily, our Earth has a source of light and heat which helps us maintain our lives.*" While the prior knowledge of the community was transferred to support the new inquires, some of the prior ideas were also re-examined and refined. For example, a student in Grade 6 revisited a notion many students had in Grade 5 that "greenhouse gases are bad" and clarified that "The Earth does need some greenhouse gases, but … not too much." In addition to building on content-specific ideas from the past, students also adapted their prior strategies and practices of knowledge building to support their current inquiry. In light of the findings from this and other studies, we designed a new online support—Idea Thread Mapper (Zhang et al., 2018)—to better support knowledge interaction across school years and communities.

The role of meta-knowledge about discourse in knowledge building

Carol Chan, Yuyao Tong, and Jan van Aalst

The importance of dialogue in learning, thinking and understanding in online environments is well established in the CSCL literature. Current efforts to promote classroom dialogue and productive discourse have emphasized knowledge construction–in which students elaborate their ideas, provide reasons, query others' standpoints and construct deeper understanding (Mercer & Littleton, 2007). Similarly, research on CSCL discourse has highlighted meaning making, inter-subjectivity and argumentation mediated by technology (Stahl, Koschmann & Suthers, 2014). However, discourse as an epistemic object of inquiry and a form of explicit knowledge, which students need for creative knowledge work, has received less attention.

Dialogue is pivotal as it underpins all knowledge disciplines; it is central to the development of scientific and systematic knowledge. In knowledge building, students engage in discourse similar to that which occurs in all knowledge disciplines. This discourse generates knowledge advancement; it involves the epistemic work of turning fragmented ideas into coherent explanations and theories for creative work. Current research in the learning sciences has emphasized discipline-based scientific discourse. We take the position that knowledge-advancing discourse moves beyond the expression of what is known and assertions of beliefs. Rather, it is progressive and ever-deepening with no-end-goals for creative knowledge work. Just as knowledge about knowledge (e.g., nature of science) is needed for scientific inquiry, students also need knowledge of discourse for knowledge creation. We call this meta-knowledge of discourse as it involves a meta-level of knowledge. Students' knowledge about how knowledge is created through discourse would encompass epistemic components such as goals, functions, processes and standards/criteria. Central to this paper is that students need to develop an epistemic understanding of discourse; they need to develop their meta-knowledge of discourse and deploy this knowledge for productive knowledge building.

Preliminary findings from a study by Lin and Chan (2018) indicate that 5th graders who hold richer conceptions of discourse also have deeper scientific understanding. This presentation reports on design-based studies that investigated the development, characterization and effects of meta-knowledge about discourse in knowledge building. Data were drawn from 3 classes of grade 9-10 students, building knowledge about art and design over 2 school years. We examined how students engaged in collective inquiry supported by their meta-knowledge of discourse; how meta-knowledge about discourse is manifested; and what effects meta-knowledge about discourse has on students' knowledge building. First, we created a knowledge-building environment for developing students' meta-knowledge of discourse. Students' engaged in collective inquiry and discourse about their ongoing Knowledge Forum discourse. Three views (discussions) in Knowledge Forum were designed to support inquiry about (a) visual arts, (b) the nature of discourse, and (c) collective knowledge advance. Classroom discussions typically focused on idea development; we added a meta-layer of explanation for idea improvement. Students' prior knowledge about discourse was prompted through their analysis of Knowledge Forum discourse threads. Students engaged in meta-discourse using their knowledge about discourse to explain why and how certain Knowledge Forum inquiry is productive and what needs further knowledge work.

Knowledge about domain inquiry and nature of discourse was intertwined. Students also generated epistemic criteria and standards that were inquired into in relation to knowledge-building principles; their meta-knowledge about discourse was continually refined through collective inquiry. Second, multiple data including Knowledge Forum notes, interviews and open-ended questions were examined. We identified different kinds of meta-knowledge about discourse that evolved with our design: (a) epistemic goals—content-focused vs. theory building; (b) epistemic processes—interactive vs. emerging and non-ending processes; (c) epistemic criteria — creation of standards related to knowledge-building principles appropriated to their inquiry context. Students also demonstrated meta-strategic knowledge of how they could use their knowledge about principles to reflect on their ongoing inquiry. Third, students reflected on their evolving knowledge about discourse in their portfolios linking to domain knowledge. Coding showed that meta-knowledge about discourse on Knowledge Forum was associated with their portfolio scores and domain knowledge advances. Ongoing analyses are examining the interweaving of domain-specific and meta-knowledge of discourse for sustained growth. This study suggests the need to scaffold students' explicit knowledge about discourse and meta-level explanations for productive knowledge-building.

Deepening knowledge of knowledge building

Seng Chee Tan

For more than three decades, researchers working on knowledge building have benefited from the theory and principles of knowledge building (Scardamalia, 2002; Scardamalia & Bereiter, 2015). In the spirit of knowledge building and taking a meta-level view, we could apply the *rise above* principle to knowledge building research to improve our understanding of knowledge building. One approach is to work within the 12 principles, apply and study learning design based on these principles of knowledge building with the ultimate goals of improving practices and gaining deeper understanding of these principles. This is the approach that much of research on knowledge building has taken. An alternative approach is to look beyond the knowledge building literature for innovative integration of ideas, which in essence, widens our resources for improving theory of knowledge building.

Examining beyond the knowledge building literature, we could identify at least two other perspectives of knowledge creation: organizational knowledge creation theory by Nonaka and Takeuchi (1995) and expansive learning in cultural-historical activity theory by Engeström (1999). A comparison of these different perspectives reveals differences in terms of their contexts, actors of knowledge creation, driving forces for knowledge creation, types of outcomes of knowledge creation, and knowledge creation processes (Tan & Tan, 2014). Paavola, Lipponen, & Hakkarainen (2004), for instance, examined knowledge building with these perspectives of knowledge creation and identified the critical roles of mediating artifacts in knowledge creation, leading to the development of principles for *trialogical* learning. We could extend such effort further to explore other questions. For example, the interplay of tacit and explicit knowledge forms the core of organization knowledge creation theory by Nonaka and Takeuchi, but the roles of implicit knowledge is not well explored in knowledge building literature. Current research tends to focus on explicit codified knowledge, which also forms the core of trialogical learning. Bringing the notion of tacit knowledge into knowledge building research triggers a series of questions: What roles does tacit knowledge play in knowledge building? Can tacit knowledge be codified and shared? Can we bypass the codification process to share and 'build on' tacit knowledge? If so, how should we design learning environments to facilitate this process? The issues of tacit knowledge has been discussed to some extent in the field of organization knowledge creation. Nonaka and von Krogh (2009) summarized some of the debates and clarified their positions. In essence, they take the view that not all tacit knowledge can be codified; tacit and explicit knowledge are on the same continuum and they play complementary roles. Nonaka and von Krogh acknowledge the social practice views (e.g., community of practice) of how implicit rules and knowing can be formed through apprenticeship or mentoring within a community, but presented the challenge of achieving the dual goals of conserving existing social practices versus achieving innovation and knowledge creation.

What do all these mean to knowledge building? As a start, they could provide inspiration to expand our research agenda. First, if we acknowledge that tacit and explicit knowledge co-exist in most learning situations, besides examining students' knowledge artefacts, we may want to explore other "tacit aspects" of learning in knowledge building. For example, in many knowledge building studies, field trips or group hands-on activities were included. Do these personal experiences relate to learning beyond those that can be examined through the students' knowledge artefacts? How do students feel as they engage in knowledge building and how do teachers feel as they facilitate the process (emotions in learning)? Do their feelings relate to the cognitive aspects of learning? Do students develop the identity of a knowledge builder? Second, if tacit knowledge can't be codified

totally, how do we design learning environments to facilitate such process? For subjects such as music and singing, which requires tacit embodied skills (exercising body internal "organs" to produce melodious voice), how do we support idea improvement? Would multimodal representations work? If so, how do we provide scaffolds in multimodal representations? Third, could knowledge building offer solutions to other perspectives of knowledge creation? For example, the practice of always seeking for idea improvement and rising above current level of understanding from knowledge building could be a possible approach to overcoming the challenge of "preserving culture and practices" versus innovative work suggested by Nonaka and von Krogh (2009).

Meta-knowledge to strengthen epistemic agency
Marlene Scardamalia and Ahmad Khanlari

Knowledge Building as an educational approach has always emphasized turning progressively higher levels of agency over to students in the conduct of knowledge creation. This generally requires that students take a higher-level view of their work, which can be facilitated both by providing supports such as scaffolds and information they can discuss and formulate into "meta-knowledge" about their own knowledge building and about the problem domain in which they are working. In this symposium, Chan, Tong, and van Aalst report beneficial results from supporting students' development of meta-knowledge about their knowledge-building discourse. In our laboratory, experiments have shown that children as young as age seven can make productive use of information about their use of Knowledge Forum "scaffolds" and about the domain vocabulary they are using and how this compares to the vocabulary used by experts (Resendes, Scardamalia, Bereiter, Chen, & Halewood, 2015). They can also profit from identifying "promising" ideas and making these objects of discussion (Chen, Scardamalia, & Bereiter, 2015). Research still in the offing will investigate ways students can make use of social and semantic network data in enhancing individual contributions to collective efforts (cf. Ma, Matsuzawa, Chen, & Scardamalia, 2016). Research to be reported in this symposium deals with students' knowledge of misconceptions and the role this meta-knowledge can play in their knowledge building.

This research falls within the general area of "intentional conceptual change" (Sinatra & Pintrich, 2003). In a preliminary study we examined student use of scaffolds such as "*I need to understand*" and "m*y problem of understanding*" to determine if students expressed uncertainty about ideas and theories they recorded in Knowledge Forum. Analyses suggest students have untapped awareness of misconceptions. Follow-up research will engage grade 5-6 students in identifying misconceptions about electricity in records of the online work of similar students in previous years. They will then carry out knowledge building of their own in this area, in an experiment that tests the effects of providing students with general versus domain-specific prior knowledge of common misconceptions. Our hypothesis is that providing students with the kinds of knowledge about misconceptions normally available only to their teachers will result in students taking an active role in preventing and remediating scientific misconceptions.

The role of domain-specific principled practical knowledge (PPK) in knowledge creation
Carl Bereiter

When attention shifts from individual knowledge acquisition to extended programs of knowledge creation, challenges to creative thinking begin to take the form of obstacles, anomalies, and unsolved problems. Accordingly, the knowledge most needed for progress tends to be domain-specific and practical rather than generic or theoretical. This is what Bereiter (2014) has called "principled practical knowledge" or "PPK" and defined as "explanatorily coherent practical knowledge." PPK is knowledge that, while not itself theoretical, meets scientific standards of coherence with empirical evidence and explanatory propositions in a domain. PPK is relevant to societal needs for creativity in two ways. First, many of the most important products of creative thinking are PPK—generalizable solutions to practical problems. Second, people need PPK that is helpful in their own creative work, PPK that enables them to go beyond brainstorming and tinkering. That is the role of PPK sketched here.

Although commercial booklists are full of books intended to help people do better, little of the knowledge conveyed is both principled and practical. Especially where creative work is involved, the principled and the practical seem to occupy different realms. There are, however, a few exceptions. Three examples are:

(1) Polya's (1957) mathematical problem solving heuristics. These heuristics are very general, involving no particular mathematical knowledge. However, applying them well always requires linking them to

mathematical knowledge. Drawing a diagram or picture, for instance, can be helpful or misleading, depending on how well it reveals the essence of the problem. Polya used as an example solving a problem concerning the length of a diagonal in a three-dimensional space figure. A diagram could suggest right triangles as the source of missing values, but it is unlikely that, without some guiding concept, a student would draw a figure suggestive of this solution path. A more specific heuristic, useful in a variety of spatial and figural problems, both hypothetical and real-life, is *look for right triangles.* This is a different order of practical knowledge from the process-oriented heuristics of Polya and much of conventional instruction in creative thinking. Yet it is the kind of practical knowledge, closely tied to disciplinary knowledge, that can directly aid problem solving.

(2) Rhetoric. Many works intended to help people writer better convey practical knowledge in the form of principles, but not "explanatorily coherent" ones. Instead, their advice is distilled from experience and supported by examples. In contrast, the work of Christensen (1968) provides an example of what PPK in writing might be. Christensen observed that the sentences of expert writers were distinguished by heavy use of "free modifiers"—modifying clauses or phrases put outside and usually after the main clause, rather than embedded in it. This finding led to an explicit rule: If you want to improve readability, avoid long noun clauses and instead modify the subject by attaching free modifiers at the end. As with Polya's heuristics, this item of practical knowledge requires domain knowledge (in this case, syntactical) if one is to use it effectively.

(3) TRIZ. There is a substantial and growing body of domain-specific PPK for dealing with obstacles encountered in engineering design and invention. Called "TRIZ," it is based on a set of 40 "principles," derived by Altshuller (1984) from analyzing thousands of patents (which are creative almost by definition, being "non-obvious" solutions to problems). The principles are at about the same level of specificity as Polya's "heuristics." These, however, are refined into more specific heuristics adapted to particular problem areas. Two of the principles are "intermediary" and "cheap short-living objects." Orloff (2013, pp. 71-75) showed how these can be applied to the problem of driving concrete pilings into the ground without damaging the pilings. The "intermediary" principle suggests putting something between the driver and the piling; the "cheap short-living objects" principle suggests sand. From that point on, straightforward engineering leads to a practical solution. Homer-Dixon (2006) has gone farther in the TRIZ direction by identifying solution paths capable of generating the know-how required for tackling civilization-threatening problems. TRIZ-type knowledge would find uses in education at the school level, especially in helping "maker" projects create new knowledge. What these examples suggest is that if useful PPK for knowledge creation is to be developed it will be within specific domains and will come about through analysis of problems and solutions occurring within those domains.

The role of teachers' design knowledge in promoting creative work with knowledge and ideas

Huang-Yao Hong, Pei-Yi Lin, Ching Sing Chai, Chin-Chung Tsai, and Yibing Zhang

Design mode of thinking is the central epistemic stance that the Knowledge Building pedagogy rests upon (Bereiter & Scardamalia, 2003). To foster such epistemic stance in teaching and learning, teachers need to themselves adopt such a stance in lesson design and enactment. Teacher education focused on lesson content and activities does not normally meet this need. Instead, we propose that teacher education should be conceptualized and operationalized to foster teacher's design fluency, where design knowledge is prioritized over curriculum specified teaching knowledge, recognizing and extending idea promisingness as the key competence and epistemic/pedagogical framing as the means for responsive Knowledge Building. Building on our research and experience in helping teachers develop design knowledge over the past 10 years in Taiwan, Singapore, and China, in this presentation, we will (1) propose a conceptual framework to foster teachers' design knowledge for Knowledge Building, and (2) showcase how design thinking by teachers leads to design thinking by their students.

McKenney, et al. (2015) define design knowledge as "different kinds of knowledge resources and aspects of knowing that enable intelligent and fluent design work by teachers across situations and contexts" (p.7). There are three essential features outlined in this definition: design knowledge resources, design thinking as a way of knowing, and design fluency. Corresponding to Chai, et al.'s (2018) idea of technological pedagogical and content knowledge (TPACK), we identify three main types of knowledge resources for teachers to engage in productive design work, including the heuristics about the 12 Knowledge Building principles (Scardamalia, 2002), technological knowledge about Knowledge Forum tools, and the generic curriculum knowledge and specific subject matter knowledge. We posit that whether teachers are able to responsively and flexibly draw upon various types of knowledge sources to design Knowledge Building activities for students is a key to effective lesson design.

Second, design thinking as a way of knowing can be developed using ideas drawn from existing design schools, such Stanford's D. School. Examples could include (1) empathizing with students' potential for and difficulty in Knowledge Building; (2) defining and progressively solving emerging problems derived from student Knowledge Building; (3) continually generating and tinkering with diversified design ideas; (4) producing and refining lesson design as a prototype; (5) testing, reflecting, and redesigning for further improvement of previous lesson design.

Third, design fluency can be manifested in the evolutionary process of teachers' design ideas (Hong & Sullivan, 2009), especially within a teacher community where teachers work together to reflect on their actions and practices in fostering Knowledge Building. During iterative lesson design, enactment, and reflective consolidation process, teachers' design fluency are embodied in the forms of design talk, feedbacks, and explanations to support students' Knowledge Building activities during co-design discussion. The development of design ideas can change over time both in quantity and quality. Quantitatively, we expect that there will be diversified design ideas proposed and shared within teachers' design community. Qualitatively, we assume that there will be progressive rise-above effort to produce more promising design ideas emerging from teachers design talks, feedback, reflection, etc. Efficiency of producing diversified ideas and efficacy of improving the explanatory coherence of design ideas will be two critical dimensions to measure teachers' design fluency. At the same time, whether teachers are able to bring the three types of knowledge sources mentioned above into a more integrated design knowledge also plays an important role to assess their design fluency for fostering effective Knowledge Building activities.

Eventually, as outcomes of sustained design activities, we expect teachers to gradually develop what Hatano and Inagaki (1986) called "adaptive expertise" on one hand and more informed design epistemology on the other hand. As for students, we expect that teachers' design effort would lead to invention and knowledge creation by their students (Lahti & Seitamaa-Hakkarainen, 2014).

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research, 81* (2), 132-169.

Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, NJ: Lawrence Erlbaum Associates.

Bereiter, C. (2014). Principled practical knowledge: Not a bridge but a ladder. *Journal of the Learning Sciences, 22*, 4-17.

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. D. Corte, L. Verschaffel, N. Entwistle & J. v. Merrienboer (Eds.), *Unravelling basic components and dimensions of powerful learning environments* (pp. 55-68). Oxford, UK: Elsevier Science

Chai, C. S., Koh, J. H. L., & Teo, Y. H. (2018). Enhancing and modeling teachers' design beliefs and efficacy of technological pedagogical content knowledge for 21st century quality learning. *Journal of Educational Computing Research*. https://doi.org/10.1177/0735633117752453.

Chen, B., Scardamalia, M., & Bereiter, C. (2015). Advancing knowledge building discourse through judgments of promising ideas. *International Journal of Computer-Supported Collaborative Learning, 10* (4), 345-366.

Engeström, Y. (1999). Innovative learning in work teams: Analyzing cycles of knowledge creation in practice. In Y. Engestrom, R. Miettinen, & R. L. Punamaki (Eds.), *Perspectives on Activity Theory* (pp. 377–404). Cambridge: Cambridge University Press.

Hatano, G., & Inagaki, K. (1986). Two courses of expertise. In H. Stevenson, H. Azuma & K. Hakuta (Eds.), *Child development and education in Japan* (pp. 262-272). New York: W. H. Freeman and Company.

Hoadley, C. M. & Linn, M. C. (2000). Teaching science through online peer discussions: SpeakEasy in the Knowledge Integration Environment. *International Journal of Science Education*, *22*, 839-857.

Hong, H. Y., & Sullivan, F. R. (2009). Towards an idea-centered, principle-based design approach to support learning as knowledge creation. *Educational Technology Research and Development, 57*(5), 613-627.

Lahti, H., & Seitamaa-Hakkarainen, P. (2014). Designing teaching—teaching designing: Teacher's guidance in a virtual design studio. Journal of Learning Design, 7(1),10–26.

Lin, F., & Chan, C.K.K. (2018). Promoting elementary students' epistemology of science through computer-supported knowledge building discourse and epistemic reflection. *International Journal of Science Education*, *40* (6), 668-687.

Ma, L., Matsuzawa, Y., Chen, B., & Scardamalia, M. (2016). Community knowledge, collective responsibility: The emergence of rotating leadership in three knowledge building communities. In Looi, C. K., Polman, J. L., Cress, U., and Reimann, P. (Eds.). *Transforming learning, empowering learners: The*

International Conference of the Learning Sciences (ICLS) 2016, Volume 1, pp. 615-622. Singapore: International Society of the Learning Sciences.

McKenney, S., Kali, Y., Markauskaite, L., & Voogt, J. (2015). Teacher design knowledge for technology enhanced learning: an ecological framework for investigating assets and needs. *Instructional science, 43*(2), 181-202.

Mercer, N. & Littleton, K. (2007). *Dialogue and the development of children's thinking: A sociocultural approach*. London: Routledge.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge creating company: How Japanese companies create the dynamics of innovation.* New York, NY: Oxford University Press.

Nonaka, I., & von Krogh, G. (2009). Tacit knowledge and knowledge conversion: Controversy and advancement in organizational knowledge creation theory. *Organization Science, 20*(3), 635-652.

Orloff, M. A. (2013). *Inventive thinking through TRIZ: A practical guide.* New York, NY: Springer.

Paavola, S., Lipponen, L., & Hakkarainen, K. (2004). Models of innovative knowledge communities and three metaphors of learning. *Review of Educational Research, 74*(4), 557–576.

Resendes, M., Scardamalia, M., Bereiter, C., Chen, B., & Halewood, C. (2015). Group-level formative feedback and metadiscourse. *International Journal of Computer-Supported Collaborative Learning, 10*(3), 309–336.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago: Open Court.

Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences (2nd ed.)* (pp. 397-417). New York: Cambridge University Press.

Sinatra, G.M., & Pintrich, P.R. (Eds). (2003). *Intentional conceptual change*. Mahwah, NJ: Erlbaum.

Simonton, D. K. (1999). *Origins of genius: Darwinian perspectives on creativity*. New York: Oxford University Press.

Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.

Stahl, G., Koschmann, & Suthers, D. (2014). Computer-supported collaborative learning. In R.K. Sawyer (Ed.) *The Cambridge handbook of the learning sciences* (pp. 479-500). Cambridge: Cambridge University Press.

Tan, S. C., & Tan, Y. H. (2014). Perspectives of knowledge creation and implications for education. In S. C. Tan, H. J. So, & J. Yeo (Eds.), *Knowledge creation in education* (pp. 11-34). Singapore: Springer.

Zhang, J. (2009). Toward a creative social web for learners and teachers. *Educational Researcher, 38*, 274-279.

Zhang, J., Tao, D., Chen, M-H. Sun, Y., Judson, D., & Naqvi, S. (2018). Co-organizing the collective journey of inquiry with Idea Thread Mapper. *Journal of the Learning Sciences, 27*, 390-430.