Enhancing the Social and Cognitive Benefits of Digital Tools and Media

Thérèse Laferrière, (Chair), TACT, Faculty of Education, Laval University, Quebec City, Quebec, G1V 0A6, tlaf@fse.ulaval.ca
Marjut Viilo, Pirita Seitamaa-Hakkarainen, Centre for Research on Activity, Development, and Learning (CRADLE), Department of Teacher Education, P.O. Box 9, SF-00014 University of Helsinki,
Email: marjut.viilo@helsinki.fi, pirita.seitamaa-hakkarainen@helsinki.fi
Kai Hakkarainen, Department of Education, Assistentinkatu 5, 20014 University of Turku, kai.hakkarainen@utu.fi
Jun Oshima, Shizuoka University, 3-5-1 Johoku, Hamamatsu-shi, Shizuoka 432-8011, Japan, joshima@inf.shizuoka.ac.jp
Marlene Scardamalia, Carl Bereiter, Bodong Chen, Maria Chuy, Monica Resendes, Institute for Knowledge Innovation and Technology, University of Toronto, 252 Bloor Street West, Toronto, Ontario M5S 1V6,
Email: marlene.scardamalia@utoronto.ca, carl.bereiter@utoronto.ca, bodong.chen@gmail.com, maria.chuy@utoronto.ca, monica.resendes@utoronto.ca
Jan van Aalst, Carol Chan, Faculty of Education, University of Hong Kong, Pokfulam Road, Hong Kong, SAR, China,
Email: vanaalst@hkucc.hku.hk, ckkchan@hku.hk
Katerine Bielaczyc, National Institute of Education, Learning Sciences Lab, Block 2 Level 3 Room 72, 1 Nanyang Walk, Singapore 637616, kateb369@gmail.com
Huang-Yao Hong, National Chengchi University, 64, Sec 2, ZhiNan Rd., Wenshan District, Taipei, 11605, Taiwan, hyhong@nccu.edu.tw
Jianwei Zhang (Discussant), State University of New York at Albany, 1400 Washington Ave., Education 115B, Albany, NY 12222, USA jzhang1@albany.edu

Abstract: While new media have greatly magnified people's opportunities for access to and sharing of knowledge and ideas and for forming social networks they have not performed so well as media for the collaborative production of new knowledge. In this symposium, researchers with experience in efforts to advance knowledge building apply insights they have gained to the question of how to enhance the socio-cognitive benefits of new media. We suggest development of a technological, social, cognitive and epistemic infrastructure for creative knowledge work. Toward this end we propose engaging teachers in design research along with researchers and subject-matter experts, enhancing students' ways of contributing to the pursuit of causal explanations, and introducing technological advances that provide greater support for high-level knowledge processes. We argue that teachers and students must be major players in the design and working of an infrastructure for creative knowledge work.

Focus of the Symposium

New digital tools and media are having a transformative effect on the way people form relationships, process information, reach decisions, and share and generate knowledge and ideas. Nevertheless, shortcomings have become evident. The most conspicuous, from a socio-cognitive standpoint, is the absence of the kind of sustained collaborative discourse that solves problems and builds new understandings. Tweets are not a way to advance what Homer-Dixon (2000) has called "ingenuity"—the supply of explicit know-how available for use in problem solving. The wildly popular social sites, such as Facebook, connect people but they cannot really be said to connect ideas, much less to support sustained elaboration and improvement of ideas. Open Educational Resources and *Wikipedia* provide individuals with extraordinary access to existing knowledge, but the potential of collaboration to help internalize, apply, and extend this knowledge gets little technological support. It is easy to attach a discussion board to any online document, but the resulting discussions tend to be too localized to produce sustained idea development. We occasionally see sustained idea development in blogs, but this is usually because the blogger has chosen to use the medium as a thinker's notebook. Typically such blog entries are monologues, sometimes with comments from others, sometimes not.

The preceding criticisms are personal impressions. Except for discussion threads, which have been around long enough to become objects of socio-cognitive research (e.g., Hewitt, Brett & Peters, 2007; Hewitt & Brett, 2007), there is little firm evidence to support them. However, the focus of this symposium is not on criticism but on constructive dialogue. Assuming that there is always room for improvement, this symposium will focus on ways to enhance social and cognitive benefits, both through the design of technology and through improvements in the way it is used in education. In approaching the problem of enhancing socio-cognitive benefits of new media, this symposium will focus on what appears to be a crucial missing element: support for sustained, collaborative, problem-solving dialogue centered on ideas rather than on the documents or other media artifacts that embody them. The symposium brings together researchers and innovators who have different perspectives on how to bring more collaborative learning and knowledge advancement into the use of new social and knowledge media. Viilo, Seitamaa-Hakkarainen, and Hakkarainen discuss the kinds of learning experience students need in order to get to the point where they can sustain knowledge-building dialogue independently. J. Oshima, Yamaguchi, Nakayama, Inagaki, R. Oshima, Sakamoto, and Yamamoto consider the crucial role of the teacher's epistemology in determining how digital tools and media will be used in classroom learning and knowledge building. Bereiter, Chen, Chuy, Resendes, and Scardamalia discuss classroom interventions and software tools aimed at engaging students in identifying and elaborating the kinds of "big ideas" increasingly called for in educational standards.

Organization of the Symposium

Panelists will discuss theoretical underpinnings of their recommended means for enhancing the socio-cognitive benefits of digital tools and media. They will identify top-level concerns and proposed solutions for remedying the situation, with the audience engaged in discussion and analysis of both the conceptual framework and proposed solution. The discussant is deeply involved in research in this area and will engage the audience in this highly interactive session.

Contributors and Presentations

The Teacher's Role in Developing the Socio-cognitive Infrastructure for Progressive Collaborative Inquiry (Viilo, Seitamaa-Hakkarainen, & Hakkarainen)

Few would question that realizing the cognitive benefits of new knowledge media depends on having them incorporated into effective knowledge practices. What is less well recognized, however, is that acquiring these knowledge practices represents for students a higher-order educational achievement in its own right, and it may require long-term guidance by skilled teachers using pedagogy appropriate to the task. Many knowledge building studies unintentionally give the impression that students could engage in collaborative knowledge advancement on their own. They report students' great achievements and leave aside the teacher's guiding role or the value of suitable classroom practices (Hakkarainen, 2009). When teachers try to implement knowledge building in their classrooms, they may become discouraged when students initially fail to pose meaningful questions, generate relevant intuitive theories, or engage in productive discourse interaction. Many intended knowledge building experiments neither facilitate genuine inquiry nor demonstrate knowledge advancement. Advancement of local knowledge-building communities occurs when the teacher iteratively works to transform local classroom practices toward inquiry-based ones, involving students' participation in collaborative knowledge building. There are clear needs for research on productive pedagogical practices concerning collaborative inquiry.

In addition to a *technological infrastructure* and a suitable *social infrastructure*, progressive collaborative inquiry requires an *epistemic infrastructure*, within which knowledge is treated as something that can be shared and jointly developed by participants, and a *cognitive infrastructure* of knowledge practices—ways of working with knowledge and ideas and their embodiments in various media objects. Hakkarainen and colleagues have developed a pedagogical model of progressive-inquiry (PI) learning model (Hakkarainen, 2003; 2004), inspired by Scardamalia and Bereiter's (2006) knowledge-building framework. The PI model is a tool that assists teachers in engaging their students in expert-like creative knowledge practices. The idea is that the teachers should guide students themselves to assume responsibility for all aspects of inquiry, such as goal-setting, questioning, explaining, and evaluating; they must guide students' process of inquiry by their own example. The model consists of several elements that constitute essential aspects of a cyclic process of solving problems and advancing local, collective knowledge. *Shared expertise* means that the participants of knowledge creating inquiry are not isolated individuals but a classroom learning community that pursues joint investigation by sharing all elements of progressive inquiry. *Construction of working theories* guides the participants to stretch their knowledge and understanding for creating shared epistemic artifacts for supporting subsequent inquiry efforts. By *critically evaluating* their advancement, individuals, teams, and the whole inquiry community are able to focus their subsequent inquiry efforts toward promising directions. The question-driven process of inquiry provides heuristic guidance in the *search for new information* for directions and sources not determined by the teachers or initially anticipated by the participants. The process of inquiry starts with initially very general, unspecified and "fuzzy" questions and tentative working theories; advancement of inquiry entails that the participants focus on improving their ideas by *generating more specific questions* and searching for new information for directing further investigations (Hakkarainen & Sintonen, 2002).

In this presentation we trace the work of one teacher in implementing this model so as to establish among the students the knowledge practices constituting a *social, epistemological,* and *cognitive infrastructure* for progressive collaborative inquiry. The teacher assumed the role of organizer concerning collaborative progressive inquiry and designing activities. This was based on continuous following of the pupils' current state of inquiry process. The teacher diary revealed the epistemic infrastructure when she is concerned with how to guide and support students' deepening inquiry and how to encourage them to propose *why* questions without guiding them too much. In the social infrastructure she considered the students' teams' activities and their interaction. During the project she reflected on individual student's roles, highlighted their special areas of expertise, and supported creation of collaborative culture. In terms of developing methods of creating and sharing views and making collective discussion notes during the process, she constructed a technological infrastructure based on inquiry use of Knowledge Forum. Knowledge Forum structured the process and mediated activities, and rendered knowledge objects visible and accessible to the whole learning collective. Successful knowledge-building cultures are usually based on single classes in which there is an exceptionally motivated and committed teacher (Hakkarainen, 2009); this was, indeed, the case in the present study. We suggest that in order to expand and scale-up advanced inquiry practices, the teacher's usually invisible work in guiding and directing classroom practices has to be made visible and analyzed in detail.

Teacher Epistemology and Constructive Uses of New Media (J. Oshima, Yamaguchi, Nakayama, Inagaki, R. Oshima, Sakamoto, and Yamamoto)

Teacher development is imperative if the potential socio-cognitive benefits of new media are to be realized in classrooms. However, it would be a mistake to limit teacher development to uses of the new media. How technology is used in classrooms will be to a large extent determined by how teachers integrate it into subject-matter instruction, and this in turn will be much influenced by the teachers' knowledge of the discipline and their epistemology as it relates both to disciplinary practice and to learning (Duschl & Wright, 1989; Lederman, 1992; Tobin & McRobbie, 1997). In their investigation of high school teachers' planning and teaching science, Duschl and Wright (1989) found that the teachers made their decision in the selection, implementation, and development of instructional tasks significantly based on student development, curriculum guide objectives, and pressures of accountability. The teachers were found to give no consideration to the nature or role of scientific theories or structure of the subject matter. They concluded that such significant deficiency in teachers' decision-making in the science classroom can be explained by their lack of knowledge about the nature of science. A case study of one science teacher by Tobin and McRobbie (1997) found that the students' and teacher's goals for the course were perfectly congruent with each other, although at variance with those of the intended curriculum, and that as a result significant change in instruction was resisted by students as well as the teacher. In our work, we have applied design-based research to teachers' professional development, focusing specifically on their epistemological perspective on learning. We collaboratively participated in design-based research practice with several Japanese teachers for more than 10 years. Here, we describe the first three years of our experiences with one teacher, Teacher Y, who showed a critical shift in his epistemological perspective on learning. Our design-based research team consisted of several school teachers, learning scientists, science education researchers, and domain experts from four different institutions. As a team we designed two lesson units a year for an elementary school science curriculum. In his first design-based research, Teacher Y participated in the practice by primarily watching design meetings, colleagues' practices while taking field notes, and attending post-practice meetings. In addition to taking the observer role, Teacher Y was required to report what happened during students' activities in each class and what he thought about the practice. Analysis of video records of the design meetings and interviews revealed that Teacher Y interpreted the classroom practice based on his pre-existing epistemological perspective of learning; he was not concerned with issues that researchers focused on.

In the course of designing subsequent science units, however, Teacher Y came increasingly to adopt a new epistemological stance, which carried over into his classroom practice and his use of technology. During his teaching, Teacher Y monitored students' activities in the classroom intensively, and worked on supporting them by engaging in knowledge building discourse. In his report on a class, he described his reflection on how to use Knowledge Forum® as follows:

> When I built on notes by students, *I kept in mind that I should regularly suggest conceptual links between notes.* For instance, I wrote "Your notes may be related to the notes of Group 5, so I think you may find interesting ideas from their notes." I also encouraged students when they revised their notes based on others' comments. When they forgot to revise their ideas even if they had comments from other classmates, I reminded them to revise their notes. I hope that *my scaffolding would facilitate knowledge building discourse online*.

From his report on how to support students' knowledge building discourse, we found that his suggestions given to students were based on principles of knowledge building such as *symmetric knowledge advancement in knowledge building* ("I kept in mind that I should regularly suggest conceptual links between notes"), and *improvable idea* ("I hope that my scaffolding will facilitate knowledge building discourse online"). In our interview with him, Teacher Y further suggested that he was intentionally attempting to apply his new epistemological understanding to his teaching practice in the classroom. He recognized that he could integrate the new epistemology acquired through his participation in the design-based research practice with his pedagogical content knowledge.

> For two years, I have been working with learning scientists like Professor O. The opportunity to participate in this research project was really helpful for me to *link the new theoretical perspective on learning to what I would always like to do in the classroom such as facilitating student understanding through collaborative learning.* Now, I have a theoretical background on knowledge building behind what I am doing in the classroom. This is very powerful.

What proved to be quite profound changes in Teacher Y's epistemology and teaching practice did not come about through professional development focused on teacher beliefs and understandings but rather through participation in research-based design in collaboration with people who operated according to a more constructivist epistemology. This suggests that "learning by doing" and knowledge building principles such as *epistemic agency* and *knowledge building discourse* can apply as much to professional development as they do to classroom learning.

Causal Explanation: A Way to Achieve Greater Cognitive Benefits from Knowledge Media (Resendes, Chuy, Chen, Bereiter, & Scardamalia)

Causal explanation is an essential part of disciplinary understanding. This means that a large part of school subject-matter only becomes useful to the extent that students understand how facts are connected causally. Inquiry approaches in education put heavy emphasis on students' own pursuit of understanding, and in this context it means students trying, usually in collaboration with other students, to produce coherent and factually valid explanations. The research to be reported in this session explores ways to raise the level of students' explanations and the explanatory coherence that they are able to bring to their collective work. Assuming that most explaining is done interactively—that is, through dialogue—the research focuses on kinds of contributions students can make that move explanation-building dialogue forward. It starts with work in the field of science and then extends to work in history, with results informing designs of new knowledge media to increase students' repertoires for knowledge-advancing conversations

Explanatory coherence, as defined and computationally modeled by Thagard (1989, 2006), involves both coherence among explanatory propositions and coherence with acknowledged facts. Also known as reasoning to the best explanation, it has mostly been studied in relation to scientific theories, but McCullagh (1984) has given it a central place in historical reasoning as well. Explanatory coherence can include both "hot" and "cool" cognition (Thagard, 2006) and can deal with causation in terms of human motives and actions as well as impersonal forces (Read & Marcus-Newhall, 1993; Thagard & Kunda, 1998). Explanations can take narrative as well as paradigmatic (*e.g.,* argument) forms (Bruner, 1986). The "qualitative models" that precede formalization in science often take narrative form (Bobrow, 1985), and for young students scientific explanation often goes no farther than construction of a coherent narrative, and thus is not fundamentally different from explanatory narrative in history. Accordingly, explanatory coherence provides a common framework for evaluating dialogue in science and history education and a common goal for efforts to raise the level of student discourse in these subjects.

Enhancing students' ways of contributing to the pursuit of explanatory coherence goes to the heart of creative disciplinary thinking in both science and history. Research that is in an early stage in our research team is seeking to catalogue distinctive ways that individual students can contribute to explanation-seeking discourse. Examples of types of contributions that have a generally positive effect in moving a discussion toward coherent causal explanations are distinguished from ones that have little or negative effect. This work is setting the stage for the next stage of research in which feedback will be provided to students regarding ways of contributing toward more positive effect. In this phase we experiment with more targeted interventions designed to boost the level and quality of students' contributions to explanation-seeking discussions. Planned interventions include use of analytic assessment tools which students can call up on their own, "seeding" discussions with types of contributions the students are neglecting, and enlisting the students in developing the catalog of contribution types and the visualizations being developed to illustrate them. Through this research we hope to provide ways of achieving deeper mastery of core school subjects and boosting the quality of student discourse. The research should furthermore help in equipping students with communication and collaboration skills that will serve them in other contexts, in later education, and in knowledge work. Another outcome of the project will be a set of tools and practices that will enable others to extend this work.

Generic Improvements in Communication Technology to Enhance Socio-cognitive Gains (Chuy, Chen, Resendes, van Aalst, Chan, Scardamalia, & Bereiter)

Drawing on wide-ranging research on technologically supported knowledge building (most recently consolidated in a special issue of the *Canadian Journal of Learning and Technology*), we here discuss generic improvements in technology that could enhance socio-cognitive benefits. By "generic" we mean improvements that are not tied to any particular technology and that are potentially applicable in a variety of media environments—ranging from learning management systems to social networking sites and from wikis to video sharing sites. A companion presentation in this symposium will deal with achieving these improvements in Knowledge Forum, a software environment specifically designed to support creative knowledge processes (see Scardamalia, 2004, for detailed description).

The ideal is that any media object should be treatable as an object of inquiry and knowledge building. To a very limited extent this is done now by attaching discussion boards to such diverse objects as blog posts, news articles, and online videos. Often these become platforms for venting opinions; at best they are platforms for sharing knowledge and giving advice. Rarely, if at all, are they platforms for sustained knowledge-building discourse. It is not that such discourse is impossible, only that the technology provides no support for it. Most online communication tools adopt a conversation-oriented interaction with participants' ideas distributed across messages and responses addressing individual and oftentimes the most recent entries. It then becomes difficult for them to see the whole picture of the extended discourse and understand and review group-level progress in the community's knowledge (Hewitt, 2001; 2003). As a result, their discourse contributions are often disconnected and redundant, covering the same ground without significant progress. Generic improvements would include the following:

- Easy ways to reference other participants' ideas. With traditional threaded discourse technology, this can only be done by attaching a comment to a specific post. (Often even this facility is lacking, so that a respondent has to copy and paste part of the message being referred to. Continued discussion means further copying and pasting, to the point where the exchange becomes virtually unreadable.) Integrative knowledge building requires being able to reference several items, including different people's contributions as well as outside information sources, and to build on those.
- Ability to draw ideas together into a higher level of idea organization.
- Ability to use different media in representing ideas without segregating them into different applications; e.g., being able to incorporate a simulation into a verbal explanation.
- Rich and abundant feedback and visualization mechanisms that enable a variety of "metacognitive views" (Brown & Campione, 1996) on an unfolding discourse.

Open Education Resources (OER) (Atkins, 2007) provide a context in which sustained knowledge-building discourse would be highly desirable. Individuals now have access to educational opportunities formerly available only to students in top-flight universities. But, unless they are enrolled in some organized program, they do not have the benefit of the social supports, the knowledge sharing, and collaborative building of understanding that can be gained in a quality campus milieu. We are undertaking with collaborators at Carnegie-Mellon University experiments in merging a knowledge-building environment into their Open Learning Initiative (OLI). OLI provides not only access to quality content but also access to instructional software to support learning and exploration of that content (Thille, 2008; Lovett, 2008). Our goal is to work with their courseware designers to provide technology that encourages collaboration at a distance in achieving deeper understanding.

A case study in the OLI context will be completed in the spring of 2011. Its focus is one teacher's effort to integrate individual learning with collaborative knowledge building, and the main question is whether this effort can enhance both individual learning and group cognition (Stahl, 2006). The research includes interviews with the teacher regarding the effect on their practice from combining these environments, facilitated by being able to toggle between the individual learning and collaborative discourse environment. Analytic tools embedded in both the individual learning and collaborative discourse environments will provide a detailed picture of the student experience and help us articulate how students benefit from the different components and instructional devices. Based on results of the case study, we will consider issues such as the following: If learning is enhanced for a few students, do their contributions to the collaborative space enhance the work of the group? How can we assess growth and spread of ideas? Can we keep ideas alive and improving in a worldwide open community?

Advancing the Design of Knowledge-building Software (Chen, Resendes, Chuy, Bielaczyc, Hong, Scardamalia, & Bereiter)

Knowledge Forum is a software environment that enables coordinated use of a number of affordances for knowledge advancement, such as graphical views for meaningful note organization, facilities for citing others' work, and "rise-above" notes for producing higher-level syntheses of ideas. Four advances in Knowledge Forum design are currently under way, all aimed at further empowering users to work creatively with knowledge and ideas. These are (a) supports for capturing the key ideas in notes and flexibly characterizing them; (b) scaffolds to raise the discourse to increasingly high levels, (c) visualizations to focus attention on a subset of notes with a specific goal for advancing collective work, and (d) concurrent evaluation that can become part of an ongoing knowledge-building process. Through such means we aim to show that students can take over levels of work normally reserved for the teacher and not supported by conventional courseware.

Tagging key ideas. Multifaceted "idea tagging" helps authors identify the essence of a note and reflect on it more deeply. In turn, tags provide a more comprehensive system of note links to extend possibilities for new view creation and higher-level knowledge work. As a simple example, a keyword "wand" allows a user to highlight a word in a note. Keywords then serve as search parameters so notes sharing designated keywords can be viewed as a cluster. Similarly larger segments of text can be highlighted as "big" or "promising" ideas (labels are customizable) and searches allow these ideas to be retrieved for further development, with ideas prioritized based on number of "hits".

Scaffolds. Scaffolds that label and provide sentence-starters for various "thinking types" have been a popular and frequently imitated feature of Knowledge Forum from its earliest origins in CSILE (Scardamalia, et al., 1989). Because scaffolds are customizable they can support whatever form of discourse the community is particularly interested in--diagnoses, causes, theories, analogies, and so forth. As Chuy et al., (in press) demonstrate, scaffolds can raise the level of discourse beyond developmental expectations. And since scaffolds can facilitate after-the-fact analysis of ideas, as well as provide support for the generation of new ideas, they can be designed to support analysis of student notes *by students*. Up to this time, a simple set of theory-building scaffolds has carried the main burden of partially structuring knowledge-building discourse ("My theory…," "I need to understand…," "A better theory…," etc.). The current effort is to provide more complex scaffolding based on a model of "good moves" in problem-solving dialogue. For example, one set of scaffolds will promote a metacognitive view of the dialogue's progress. Students might use the following scaffolds to analyze their progress: "An idea that represents our point of greatest progress," "A misconception hampering progress…," "We haven't followed through with…." Note the emphasis on how "we" are doing, in contrast to the more individualistic emphasis of the original scaffolds.

Visualization. Information visualization is a powerful tool for searching, filtering, and transforming large amounts of data into a form that facilitates human interaction with it. Visualization tools being incorporated into Knowledge Forum help users explore and understand database content and facilitate the use the idea tags mentioned above. The tools also provide visualizations of social and semantic relational structures. The design challenge in using these visualizations for knowledge building is to support real-time interaction and modification of information represented in the visualization. In our experience the form of visualization users have found most helpful is one that filters out all notes other than those that meet a small number of criteria so that the visualization dramatically lowers the amount of information to be processed. For example, users might wish to bring all notes with the scaffold support "An idea that represents our point of greatest progress," forward, so what they see and work with on the screen is the small subset of notes tagged with that particular scaffold support.

Concurrent, embedded, and transformative assessment. Concurrent assessment means that the assessment is available instantaneously. Embedded means that it is integral to the workings of the organization rather than being functionally distinct. Transformative means that the evaluation is not simply an account of past performance and next immediate steps, but also provides indication of ways individuals and teams can tackle broader problems and situate their work in relation to that of other team members, including teams outside the school walls. An example of the kind of concurrent, embedded, and transformative assessment we are working on is automated detection of misconceptions. Use of Knowledge Forum in a health sciences short-course on pain management revealed the importance of being able to monitor the incidence and possible spread of misconceptions. This was done by hand coding—a slow and labor-intensive process. Automated detection, even if less accurate, would yield important benefits in alerting students and instructors to possible trouble spots. To achieve such automated detection, high-powered prior semantic analysis will contrast documents exhibiting recognized misconceptions in a domain with documents representing accepted knowledge, yielding a set of markers that distinguish the misconception laden-texts. These markers (typically specific words) may then be used in a simpler and less computationally intensive concurrent analysis to identify likely misconceptions. The possibilities for data generated automatically from student discourse and artifacts seem to have no bounds and allow a community to engage in its own internal assessment, which is both more fine-tuned and rigorous than external assessment. This then serves to ensure that the community's work will exceed the expectations set by external assessors.

Jianwei Zhang, as Discussant, will review and reflect on the socio-cultural and cognitive dynamics of knowledge creation addressed in the presentation, highlight challenges faced by teachers and students, and identify areas of technological enhancement and pedagogical research to better support idea-centered, sustained problem-solving dialogue.

References

Atkins, D., Brown, J. S., & Hammond, L. (2007). *A review of the Open Educational Resources (OER) movement: Achievements, challenges, and new opportunities*. Retrieved November 8, 2010, from http://www.oerderves.org/wp-content/uploads/2007/03/a-review-of-the-open-educational-resources-oer-movement_final.pdf

Bereiter, C. (1994). Implications of postmodernism for science, or, science as progressive discourse. *Educational Psychologist, 29*(1), 3-12.

Bobrow, D. G. (Ed.). (1985). *Qualitative reasoning about physical systems*. Cambridge, MA: MIT Press.

Brown, A.L., & Campione, J.C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds*.), Innovations in learning: New environments for education* (pp. 289–325). Mahwah, NJ: Erlbaum.

Bruner, J. (1986) *Actual minds, possible worlds*, Cambridge, MA: Harvard University Press.

Chuy, M., Scardamalia, M.. Bereiter, C., Prinsen, F. C. , Resendes, M., Messina, R., Hunburger, W., Teplovs, C., & Chow, A. (in press). Understanding the nature of science and scientific progress: A theory-building approach. *Canadian Journal of Learning and Technology.*

Duschl, R.A., & Wright, E. (1989). A case study of high school teachers' decision making models for planning and teaching science. *Journal of Research in Science Teaching, 26*, 467–501.

Hakkarainen, K. (2003). Progressive inquiry in computer-supported biology classroom. *Journal of Research in Science Teaching, 40*(10), 1072-1088.

Hakkarainen, K. (2004). Pursuit of explanation within a computer-supported classroom. *International Journal of Science Education, 24*, 979-996.

Hakkarainen, K. (2009) Three generations of research on technology-mediated learning. *British Journal of Educational Technology. 40*, 879-888

Hakkarainen, K. & Sintonen, M. (2002). Interrogative model of inquiry and computer-supported collaborative learning. *Science & Education, 11*, 25-43.

Hewitt, J. (2001). Beyond threaded discourse. *International Journal of Educational Telecommunications, 7*(3), 207-221.

Hewitt, J. (2003). How habitual online practices affect the development of asynchronous discussion threads. *Journal of Educational Computing Research, 28*(1), 31-45.

Hewitt, J., & Brett, C. (2007). The relationship between class size and online activity patterns in asynchronous computer conferencing environments. *Computers & Education, 49*, 1258-1271.

Hewitt, J., Brett, C. & Peters, V. (2007). Scan rate: A new metric for the analysis of reading behaviors in asynchronous computer conferencing environments. *American Journal of Distance Education, 21*(4), 1-17.

Homer-Dixon, T. (2000). *The ingenuity gap*. New York: Knopf.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of research. *Journal of Research in Science Teaching, 29*(4), 331–360.

Lovett, M., Meyer, O., & Thille, C. (2008). The Open Learning Initiative: Measuring the effectiveness of the OLI statistics course in accelerating student learning. *Journal of Interactive Media in Education*, *2008*(1).

McCullagh, C. (1984). *Justifying historical descriptions.* Cambridge, UK: Cambridge University Press.

Read, S.J., & Marcus-Newhall, A. (1993). Explanatory coherence in social explanations: A parallel distributed processing account. *Journal of Personality and Social Psychology, 65*, 429-447.

Scardamalia, M. (2004). CSILE/Knowledge Forum®. In *Education and technology: An encyclopedia* (pp. 183-192). Santa Barbara, CA: ABC-CLIO.

Scardamalia, M., & Bereiter, C. (2006). *Knowledge building: Theory, pedagogy, and technology.* In K. Sawyer (Ed.), Cambridge Handbook of the Learning Sciences (pp. 97-118). New York: Cambridge University Press.

Scardamalia, M., Bereiter, C., Mclean, R. S., Swallow, J., & Woodruff, E. (1989). Computer-supported intentional learning environments. *Journal of Educational Computing Research, 5*(1), 51-68.

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

Thagard, P. (1989). Explanatory coherence. *Behavioral and Brain Sciences*, *12*, 435-467.

Thagard, P. (2006). Evaluating explanations in law, science, and everyday Life. *Current Directions in Psychological Science, 15*(3), 141-145.

Thagard, P. & Kunda, Z. (1998). Making sense of people: Coherence mechanisms. In S. J. Read & L. C. Miller (Eds.), *Connectionist models of social reasoning and social behavior* (pp. 3-26). Hillsdale, NJ: Erlbaum.

Thille, C. (2008). Building open learning as a community-based research activity. In T. Iiyoshi & M. S. V. Kumar (Eds.), *Opening up education: The collective advancement of education through open technology, open content, and open knowledge*. Cambridge, Massachusetts, London, England: The

MIT Press.
Tobin, K. & McRobbie, C. (1997). Beliefs about the nature of science and the enacted science curriculum. *Science and Education, 6,* 355-371