Neuroscience, the learning sciences, and innovation

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We're all fascinated about a brain-based or neural-based explanation for what children can learn and do. But we have much more to learn from the learning sciences about educating our children than we do from brain science right now.[1] This article builds on a conversation that unfolded during the Winnipeg dialogue[2] of the Canadian Education Association and brings forward converging ideas from the learning sciences.

In about four decades, basic cognitive research has now reached a point where it generates approaches to teaching and learning that are effective and practical. Three innovative developments are key: a dramatic change in the locus of the research, the advance of new methodological tools and new conceptual tools, and new insights into ill-defined 21st century skills such as independent learning, critical thinking, and teamwork.

Cognitive science, which began in the fifties, began to give more attention to the social and cultural dimensions of education, partly as a result of Vygotsky's work.[3] This legitimized classroom-based research and, at the same time, weakened the validity of research from laboratory settings, similar to the controlled settings where neuroscience research occurs. To be true to their discoveries, some cognitive scientists took the risk, over a decade ago, of being called 'soft' scientists and moved their research from the lab to the blooming, buzzing confusion of classrooms. Today, university-based socio-cognitive researchers, classroom teachers, and students are co-investigators, tackling unsolved problems that are of central importance to their community, hypothesizing how socio-cognitive research might help solve the problem, developing a solution, and then testing and refining it in classrooms. This is an innovation in itself.

In all areas of the learning sciences, new tools and more sophisticated methodologies enable a more fine-grained analysis of complex thinking skills. Better brain-based research tools are helping us understand how the brain learns. Innovative methodologies for examining children's minds provide evidence that young learners are more and more competent. The effects of information and communication technology are already revolutionizing education according to OECD and the socio-cognitive sciences are providing important guidelines for the use of technology in schools.

For the past decade, the learning sciences have been presenting research results that are rich in new conceptual tools to the professional community of educators. These results go beyond what was learned reading Dewey, Piaget and Vygotsky, although all three would be delighted with how we have built on their work. Here are some ideas that have contributed to the evolution of the science of learning.

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What we know about learning

PRIOR KNOWLEDGE

What you learn most easily and most quickly depends on whether you have a sound understanding prior to instruction. Your prior knowledge is the best predictor of how quickly and well you will learn. Word learning is a good example: The more words you know, the more quickly you'll learn new words.

An example: Number sense

Robbie Case and Sharon Griffin looked at children who entered kindergarten with a severe deficit in numerical understanding.[4] They found that there are very specific things these children don't know. For example, they couldn't judge which of two numbers is bigger – they couldn't compare numbers for size. That's a very strong predictor of how badly they will do in early formal mathematics instruction. Case and Griffin developed a test to assess children's number knowledge prior to school, and then developed a short curriculum based on that knowledge that enabled these students to take on a typical formal early mathematics curriculum.

This research and many other studies on scientific misconceptions reveal that helping students articulate their theories on how things work opens the door to conceptual change. The well-known work showing that misconceptions are unaffected by formal instruction suggests that our schools aren't eliciting prior knowledge even though there are instructional practices, such as 'benchmark lessons', that are effective in helping students move from naive conceptions to more normative ideas.

METACOGNITION

Vygotsky's research, translated from Russian to English in the seventies, prompted researchers to study the role of the social context in learning, namely, the mediating role of language in teacher and peer learners' discourse in the classroom. Through metacognitive mediation, the teacher scaffolds or aids students, depending on their learning needs and the complexity of the domain, to increase their competence. As a student gradually takes over planning, directing, controlling, checking and assessing his learning, the teacher transfers more responsibility onto the student, and his own role is transformed into that of a skillful member in a community of learners or a knowledge building community.

An example: Reading for understanding

Poor readers have to invest more mental resources than good readers do in simply figuring out what the words are. Consequently, they have fewer resources available for understanding what they read. If they are to progress, they need not only to build up decoding skills so as to free more mental resources, but also to use those new resources to understand what they are reading.

Reciprocal teaching is one of the most successful approaches to improving reading comprehension and learning from text. In a typical session, each student in a reading group of about six members takes turns with their teacher in leading a discussion about a reading that is challenging and relevant to what the group is studying. Initially, the teacher is the leader who models effective comprehension strategies, but soon a student leader begins by asking questions about the core content and ends by summarizing the gist of the reading. As needed, the leader may ask for clarification of terms or ideas and may ask for predictions about future content. These key strategies of questioning, summarizing, clarifying and predicting help get a discussion going; but more importantly, as students become accustomed to the reciprocal teaching procedure, they begin to use the strategies during independent reading. As students become proficient with them, more complex strategies, such as using analogy and warrants, can be modeled by the teacher and then practiced by students. In an extensive battery of static and dynamic pretest and posttest measures, students who engaged in reciprocal teaching outperformed matched control groups on both factual and inferential texts.[5]

The famous "fourth grade slump" suggests that schools are not investing in scaffolding students' strategies for learning from texts. Results for older students on international tests reflect the same problem in thoroughly understanding what

RECAP

Au cours de la dernière décennie, les sciences d'apprentissage ont produit des résultats de recherche qui sont riches en outils conceptuels pour les éducateurs et éducatrices professionnels. Parmi les idées qui ont contribué à l'évolution des sciences d'apprentissage, mentionnons : les connaissances préalables qui sont le meilleur indicateur de la vitesse et de l'efficacité de l'apprentissage; la métacognition (grâce à la méditation métacognitive, l'enseignant « échafaude » ou aide l'élève à accroître sa compétence; l'intentionnalité (les enfants apprennent en construisant, en élaborant et modifiant des théories); et les communautés bâtisseuses du savoir (les élèves bâtissent leur fonds de connaissances par la lecture et l'interrogation. À noter cependant qu'il existe quelques différences importantes entre apprentissage et bâtir son savoir.

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they are reading. On average, 15% to 19% of 15-year-olds in the world's most developed countries (Australia, Canada, Finland, New Zealand and the United Kingdom) have top-level reading literacy skills, able to understand complex texts, evaluate information and build hypotheses, and draw on specialized knowledge.[6]

INTENTIONALITY

Children learn by constructing, elaborating and modifying theories. It may be that even infants have implicit theories about the world and use them.[7] Certainly, by the end of pre-school, students can be explicit about their theories.[8] By making theories visible, learners can choose and evaluate strategies, monitor understanding, and gain control of their cognitive processes. This is characteristic of expertise. Becoming an expert not only requires a great deal of domain specific knowledge, but also an intention to grapple with increasingly complex problems, subtle ideas, and self-regulative abilities. Scardamalia suggests that even young children can begin to develop expertise.[9]

An example: Writing for thinking

Using a think-aloud methodology, Bereiter and Scardamalia studied differences in the writing strategies used by expert and novice writers.[10] Although expert writers tend to be adults, there are also young expert writers and adult novice writers. What made the difference between non-experts and experts was whether they adopted a knowledge telling stance where the writer simply tells everything he knows, or a knowledge transforming strategy where the interplay between meaning what you say and saying what you mean changes both. Through guided coaching, novice writers begin to struggle with solving problems, revising their writing and taking a more metacognitive stance. This does not mean that these young writers had more fun; even expert writers find writing very demanding and effortful.

The Council of Ministers of Education, Canada (1998) found in its School Achievement Indicators Program that only 34% of sixteen year olds and 9% of 13 year olds showed "effective control of the elements of writing" (Levels 4 and 5),[11] suggesting that few children progress from knowledge tellers to knowledge transformers. Clearly, the research on becoming an expert writer has not been adopted in school instruction.

KNOWLEDGE BUILDING COMMUNITIES

Students construct their knowledge when they are learning from books or through inquiry. Here, we want to point out some important differences between learning and knowledge building. Because education and society in general is struggling to cope with the demands of the new economy, there is some interest in restructuring school activities and classroom discourse so that they resemble the workings of high-performing research groups—where a team is investigating real questions and members are trying to contribute to progress on those questions. This is knowledge building. Learning occurs in all activities directed toward gaining personal knowledge; knowledge building is activity directed toward constructing new knowledge for a community through theory construction and revision. Explicitly formulating "my theory" makes possible comparisons to other theories, tried out on relevant problems, subjected to criticism and continuous idea improvement.

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An example: Understanding Science

This setting was a class of nine and ten year olds studying biology. The young students were given the opportunity to become immersed in a culture of 'scientific inquiry' by their teacher, Caswell, who had chosen to make the Giant Madagascan Hissing Cockroach the focus of research. Caswell started with an introductory lesson to inspect the live animals, hear some facts about them, have the class take turns holding and sketching them. Each child was given a research journal, which Caswell told them was what scientists at the University of Toronto's zoological department use for observation, questions, research notes and experimental designs. Each student also learned to use Knowledge Forum® technology as an integral tool for working.[12] Initially the students used it as a graphics tool simply to draw the roaches, but gradually they were encouraged to enter one or two pressing questions into the database. Questions ranged from, 'What kind of food do they prefer?' to 'What did cockroaches evolve from?' And because these questions were stored in a database, each child's question could be 'heard'. The students found it very exciting to be adding notes to build up the database. In the course of a week 100 new notes had been entered.[13]

The following is a specific example of how students created knowledge new to their community – the idea of learned helplessness – and, as it turned out, presaged a much more recent discovery about roach behaviour at the University of Guelph.[14]

A student wrote:
"**New Information**[15]**:** Last week we did an experiment with our cockroaches based on Dr. Bell's information that roaches right themselves if they are turned over. We tested each of our 12 roaches and recorded the time it took for them to flip over. Today, I noticed that the more the roaches are handled, the less quick they right themselves.

My theory: The roaches have learned to wait for us to flip them back over.

I need to understand: Can a roach learn?"

Another student responds:
"**My theory** is that you are right that roaches can learn. And I think you have a very good experiment. But how can your experiment prove that roaches learn?"

What is particularly distinctive about this community is the use of 'public forums'. These convey to students that hands-on investigations, lab books, as well as the more complex Knowledge Forum software are integral to their work. The latter is pivotal to the whole project, providing students with a cumulative database, as well as a means of recording information and ideas. It acts as a tool for making thinking explicit, encouraging creative thinking – the making of inspired hypotheses, the articulation of probing questions, the blending of others' findings with one's own, and the intensive attempt to solve authentic problems. It might be helpful to distinguish knowledge building from project learning; the essential difference is that, although these students did create a video documentary, the idea of sharing what they knew with the rest of the school emerged from their work; it was not the starting point.

Knowledge Forum has evolved during the TeleLearning Network of Centres of Excellence years (1995-2002) to become the Knowledge Forum suite of tools. A SSHRC grant (Initiative for the New Economy, 2002) has funded an outreach activity that is disclosing circumstances under which elementary school learners are saying "My theory is…", and related innovative written and oral discourse in the classroom. Canada's education systems have recently taken the necessary steps for networked computers to be available to school learners, and early adopters of technology (teachers and school principals) are uncovering its uses. In rare instances, however, is the evidence provided by the learning sciences ever mentioned to support transformations in pedagogical practices. The rationale tends to be technology-driven, rather than theory-driven. New conceptual and technological tools must be integrated.

CONCLUSION

All learning must change the brain, but for the distinctively human forms of learning that face us in the classroom, we need to understand how human beings perceive, think, and act. This is the province of the learning sciences and all of us can take advantage of this growing knowledge base. But it will take much more dialogue between socio-cognitive and neuroscience researchers, educators and policy makers to make any difference in schooling.

1 The National Research Council (Bransford, Brown & Cocking, 1999) defines cognitive science as a "multidisciplinary perspective that includes anthropology, linguistics, philosophy, developmental psychology, computer science, neuroscience and several branches of psychology." We add sociocognitive research to this in order to refer to learning sciences.

2 See articles in this issue by Stacey Huget (page x) and Becky Matthews (page x).

3 L. S. Vygotsky, *Mind and Societgy: The Development of Higher Mental Processes* Cambridge, MA: Harvard University Press, 1978).

4 S Griffin and R. Case, "Re-thinking in the Primary School Math Curriculum: An Approach Based on Cognitive Science," *Issues in Education 3,* no. 1.

5 A. L. Brown and A. S. Palincsar, "Guided, Cooperative Learning and Individual Knowledge Acquisition" in L. B. Resnick (ed.), *Knowing, Learning, and Instrustion: Essays in Honor of Robert Glaser* (Hillsdale, N.J.: Erlbaum, 1989).

6 OECD, *Knowledge and Skills for Life* (Paris: OECD Publication Service, 2001).

7 A. Gopnik, A. N. Meltzoff, and P. K. Kuhn, *The Scientist in the Crib: Minds, Brains, and How Children Learn* (New York: Morrow, 1999).

8 J. H. Flavell, F. L. Green and E. R. Flavell, "Young Children's Knowledge about Thinking,: *Monograph, Society for Research in Child Development 60,* no. 1 (1995).

9 M. Scardamalia, Collective Cognitive Responsibility for the Advancement of Knowledge," in B. Smith (ed.), *Liberal Education in a Knowledge Society* (Chicago: Open Court, 2002).

10 C. Bereiter and M. Scardamalia, *The Psychology of Written composition* (Hillsdale, N.J.: Erlbaum, 1989).

11 Council of Ministers of Education, Canada, *School Achievement Indicators Program* (SAIP), retrieved January 7, 2002 from http:www.cmec.ca/saip/rw981e/pages/ResultsE.stm

12 Knowledge Forum, designed by Marlene Scardamalia, Carl Bereiter and a team of cognitive and computer scientists, teachers and Grade 1 to post graduate students, is a collaborative multimedia computer software program, which provides 'Notes' that represent student ideas and questions, allow these to be built on and create new syntheses of collections of related notes. 'Views' provide graphical organizers for notes that can be used to represent different ways of conceptualizing, developing knowledge base, fostering emergent goals and conceptual change.

13 Caswell and M. Lamon, "The Development of Scientific Literacy: The Evolution of Ideas in a Knowledge Building Classroom" in J. Leach and R. Moon (eds.), *Learners and Pedagogy* (London: Paul Chapman, 1999).

14 K. Honey, "Roaches: Man's Best Friend," *Toronto Globe and Mail,* 30 April 2002.

15 'Scaffolds' are built in, providing support for theory building and debating. Scaffold supports are customizable and searchable.

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