LEARNing Landscapes

Mind, Brain, and Education: Implications for Educators

Autumn 2011 Vol. 5 No. 1

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Statement of Purpose

LEARNing Landscapes™ is an open access, peer-reviewed, online education journal supported by LEARN (Leading English Education and Resource Network). Published in the autumn and spring of each year, it attempts to make links between theory and practice and is built upon the principles of partnership, collaboration, inclusion, and attention to multiple perspectives and voices. The material in each publication attempts to share and showcase leading educational ideas, research and practices in Quebec, and beyond, by welcoming articles, interviews, visual representations, arts-informed work, and multimedia texts to inspire teachers, administrators, and other educators to reflect upon and develop innovative possibilities within their own practices.

Review Board

Editorial

This issue of LEARNing Landscapes shares historically, theoretically, and practically how the fields of neuroscience, psychology, and education are working together to get a more cohesive understanding of the physiology of the brain, and to implement learning in more effective ways.

In the 1970s classroom teachers were influenced by the renewed interest in the work of pragmatist and educator, John Dewey (1916), who advocated strongly for learning by doing and for including the arts/aesthetics in education, and by the work of psychologist, Jean Piaget (1962), who demonstrated the significance of the early learning that occurs when a child interacts with his or her environment.

By the 1980s, the work of Lev Vygotsky (1978) had been translated from Russian into other languages, and educators realized that language mediates learning and, therefore, the social interaction among peers, with caregivers, and teachers, contributes significantly to how learners construct and understand their worlds. The work of psychologist Howard Gardner (1983) on multiple intelligences sent a message to the world about the need to tap into the various strengths of students and to permit them to use multiple modes for "receiving" and communicating/representing their learning. At the same time, sociolinguist and educator Shirley Brice Heath (1983) was showing not only how important it is to start the learning from where the child is and where his/her propensities lie, but also to be aware of and value where the child is coming from to enhance his or her potential.

A missing piece in the evolving understanding of learning was what was developing in the field of neuroscience, particularly in the 1990s. New and sophisticated imaging technology permitted scientists to actually see the brain at work and provided new insights about learning. It is the recent integration of mind, brain, and education (MBE) research that is helping to enhance our understanding of learning and contribute to more effective teaching. This issue illustrates many aspects of MBE work and how practice is being affected by it.

Invited commentaries

We are privileged to have commentaries from eminent scholars working at the intersection of the mind, brain, and education fields. Renate Caine, who is the executive director of the Natural Learning Research Institute, and Geoffrey Caine, who is co-director of the Caine Learning Center, both in Idyllwild, California, argue strongly for reconfiguring the "memes" of learning (ideas, behaviors, or styles that people adhere to within a culture) that have been perpetuated, and to match how the brain makes sense of experiencing by using inquiry in the classroom.

Sawyer, a professor of psychology and education at Washington University in St. Louis, kindly agreed to an interview in which he underscores the importance of creativity and collaboration in learning in order to prepare students for working lives that demand creativity, flexibility, and adaptability. He discusses with an interesting example how innovation is usually the result of collaboration rather than a particular insight of a single individual.

Sousa, who is an international consultant in educational neuroscience, an adjunct professor at Seton Hall University, and visiting professor at Rutgers University, discusses findings that have been discovered about the brain and the implications these have for learning. For example, the brain cannot multitask—it just alternates from one task to another. This increases mental effort and results in the loss of working memory for the initial task. Furthermore, emotions are what alert the brain's attention systems, and therefore, experiences that include emotions are more likely to be remembered. These three commentaries provide an excellent overview of the discussions and insights that are emerging from the integrated research on MBE and provide a framework for what follows.

The articles by the contributors to this issue are presented in the journal in alphabetical order. In this editorial, I discuss their work thematically.

History of neuroscience education

In a very helpful article, Ferrari and McBride, both teachers of psychology at the University of Toronto/OISE, trace the history of the development of the MBE field back to the work of Hippocrates (4^{th}-5^{th} century B.C.) and the philosophers that followed, to the time of the birth of and focus on developmental psychology in the work of James, Hall, Piaget, Vygotsky and others in the late 19^{th} to mid-20^{th} centuries. They attribute the emergence of the field of MBE to the likes of Hebb, Chall, and Mirsky, Gardner, Hart, Posner, and Gazzaniga. These scholars helped to move what had been educational neuropsychology into the field of MBE, which significantly emphasizes the importance of examining learning and teaching, rather than just learning and the brain. Ferrari and McBride go on to dispel some long-held "neuromyths" about the brain and make a plea for teachers and neuroscientists to work together, and to ensure that research results are made accessible to all stakeholders.

Importance of emotions in learning

Immordino-Yang, an assistant professor at the Rossier School of Education and in the Brain and Creativity Institute at the University of Southern California (USC), uses the reprint of her article with Antonio Damasio, a professor of neuroscience and the director of the Brain and Creativity Institute at USC, to lay the groundwork for her study with her young daughter, Nora Ming-Min Yang, where she analyzes longitudinally the social emotions and scientific concepts revealed in her daughter's poetry. In the original article entitled, "We Feel, Therefore We Learn: The Relevance of Affective and Social Neuroscience to Education," Immordino-Yang and Damasio discuss how emotional processes act as a "rudder" in the transfer of both knowledge and skills, that emotion plays an important and necessary role in decision making, and that it is the interface between emotion and cognition that leads to creativity. In her subsequent article, Immordino-Yang describes, with lovely examples, how her daughter Nora's developing understanding of the physical and social world is intertwined and is illustrated in her poems written from age six to age nine. In fact, Immordino-Yang suggests that she is probably compelled to write because

> By virtue of its evolutionary connection to bodily feeling and survival, our social mind motivates us to create things that represent the meaning we have made by processes of noticing, feeling, and understanding so that others can notice and feel and understand what we have. (pp. 134–135)

Ritchie, who is a consulting scientist and an adjunct faculty member at Dalhousie University in Halifax, Nova Scotia, Shore, who is an emeritus professor of psychology at McGill University, LaBanca, who is the director of the Center for 21st Century Skills at Education Connection in Connecticut in the United States, and Newman, who is an associate professor of neurology, also at Dalhousie, argue, too, that emotions have a big impact on thinking and creativity. Quick or concise thinking, often called convergent thinking, which is frequently encouraged in classrooms, has its etiology as a functional response by the brain to threatening situations. Divergent thinking, or the ability to see relationships in unconventional ways, is what is needed to innovate and problem solve in the complex and global society of today. They discuss how inquiry learning helps to encourage the latter type of thinking because it is self-directed and personal, it heightens positive emotions such as interest or excitement, and as a result "emotional valence" is increased and creativity is enhanced. They have embarked on a study using electroencephalography to collect data about how the brain can be seen to respond physiologically when participants are exposed to heightened, positive emotions and hope to relate their findings to experiences in inquiry settings.

Holistic and integrative functions of the brain

Leggo, a poet and professor of education at the University of British Columbia, describes how in the word play that takes place in creating poetry one must attend to words, sounds, shapes, and rhythms in holistic and integrative ways for the brain to produce, to be compelled to ask questions, and live with ambiguity and the "mysteries" of the world. He suggests through lovely examples how his word play portrayed in five poems illustrates the interconnections among body, brain, language, heart, and spirit, and believes this process lays the groundwork for a "pedagogy of the imagination" needed for educational well-being.

Emmerson, a PhD student at the University of Saskatchewan, describes how her experience playing music in her youth with a group known as "Martha and the Muffins" gave her pause to wonder about why music is so potent. Using the work of Levitin, among others, she describes how music has an evolutionary basis with an emotional potency because it was originally used sexually to attract a partner. Furthermore, music uses particular brain structures, including dedicated memory systems that remain functional when other systems fail. She argues that the emotional capacity of music and the memory systems it develops have much potential for integrating the intellectual, social, and emotional dimensions of education.

Focus on the adolescent brain

Willis, neurologist, international professional development educator, and former middle school teacher in Santa Barbara, California, has lived in the nexus of neuroscience, psychology, and education. I had the pleasure of hearing her present to adolescents in a local school in Montreal where she explained the fundamentals of how the brain functions and the implications of this for their studies. She zeroes in on the prefrontal cortex and how the executive functioning of this area of the brain and the branching axons and dendrites can promote conceptual thinking which includes critical analysis, judgment, prioritizing, organizing, problem solving, and long-term goal development. She advocates for stimulating the neuroplasticity of the adolescent brain in transfer tasks such as robotics to increase long-term conceptual storage. According to Hebb (1949), neurons that fire together, wire together. This has implications for classroom learning. In addition, other work shows that this idea is helpful for dealing with post-traumatic stress and addiction because "de-wiring" too is possible (Brunet et al., 2011).

Anderson, the chair of the Department of Mathematics and Science and Technology at Teachers College, and a senior research scientist at Columbia University, explores how humans encode information in memory and how it is recalled and organized in response to contextual clues. He suggests that a "contextual-label-pointer" (CLP) model shows how the frontal lobe activity of the brain organizes the construction of information in working memory guided by the rules of a particular context. He advocates that teachers use multimodal presentations and encourage multimodal representations to help students build networks of concepts and ideas that facilitate learning.

Feinstein, who is a professor and chair of the Education Department at Augustana College in Sioux Falls, South Dakota, notes that the teenage brain has a particular propensity for academic and emotional growth. Furthermore, she suggests that the current technology can be very suitable for enhancing this growth based on how the brain works. However, she cautions about the types of technology that only encourage multitasking and quick decision making. Because the chemical dopamine plays a significant role in how the brain engages in learning, but diminishes once something is learned, she encourages teachers to increase the complexity of the work as it progresses to keep students motivated.

Focus on tertiary education

MacEachren, who is the coordinator of the Outdoor and Experiential Education Program in the Faculty of Education at Queen's University in Kingston, Ontario, shares an interesting approach that she developed to help her and her university students to understand learning. Using the common practice of knitting which Waldorf educators advocate while simultaneously learning something else, MacEachren decided to have her teacher candidates learn to knit a pair of socks during a course with her (it should be noted that this would not be considered multitasking because it puts demands on different parts of the brain). She had them journal this experience in order to help them document and understand how the brain learns. She discusses how her own growing knowledge about the brain was enhanced during this process.

Now she understands more fully through practical experience how the brain is hard-wired to learn, and how its mirror neurons respond to modeling (in this case knitting), which she did with her students. Students' reflections show how they grasped these understandings and will use them in future classroom work.

Maynes and Julien-Schultz, both assistant professors at the Schulich School of Education at Nipissing University in North Bay, Ontario, show with examples how they used graphic organizers to help teacher candidates conduct their lesson planning, and how these students used reflective writing (metacognition) to explore the internalization of, and connections among, pedagogical concepts.

Kerwin-Boudreau, a psychology teacher at Champlain College in St. Lambert, at the University of Sherbrooke, and at McGill University, all in Quebec, describes how she uses a four-phase, instructional model to engage her students in designing a robot's brain. Not only do the students learn a great deal about the various parts of the brain and how the brain functions, but this inquiry assignment is also a good example of the emotional engagement it generates and, as discussed above, is required for learning.

Focus on school-based learning

Greenstone, a psychologist who is the director of the Centre MDC, an interdisciplinary care facility in Montreal, gives an overview of the basic domains of the executive functioning skills in the brain, and as others in this issue have said, she posits that these skills are extremely important for goal-directed behavior, social behaviours, and emotional well-being. She attributes a lack of these skills is often at the root of the problems that students have in school. She describes with two examples how from what is known about brain plasticity, that it is never too late to focus on and use organizers to help develop these functions in students.

Lipsett, an early childhood teacher at a Title One school in Fairfax, Virginia, discusses, using an example of a kindergarten child, how she used her knowledge of brain research to help her students be "available" for learning. She contends that young students have to first acquire the means to regulate the emotions that get in the way and prevent learning. She helps her students to observe, recognize, and label emotional responses in others and in themselves, and ultimately to draw on appropriate responses from within. She outlines the interventions she used and the success she achieved while working with seven children in a small-group, social skills session over a period of several weeks.

Rupley, who is a professor of education, Robert Capraro, who is a professor of mathematics education, and Mary Margaret Capraro, who is an associate professor of mathematics education, all at Texas A&M University, are interested in the nexus between reading and mathematical problem solving. In a review of the literature they have found little either in textbook materials or mathematic programs that ultimately enhances student achievement, but rather the best possible predictor is in how mathematics is taught. They suggest that both reading and mathematical problem solving use similar cognitive components—recognizing the patterns of text organization, generating patterns, attaining a goal (that is, recognizing if a goal has been attained or not), which they call RGA Theory. They show with examples how this theory works in practice, making a case for the interdependence and interconnectedness of reading and mathematics and suggest that children must be taught early on to "intertwine reading and mathematical cognitive strategies to make meaning of word problem-solving events" (p. 244).

Last, but certainly not least, Webster, a high school teacher at an independent school in Montreal and a PhD student at McGill University, and Bossé, who is the assistant head of curriculum and director of the centre for learning and enrichment at the same school, show, using an interesting example of one student, how they modified dramatically their perceptions about special needs students. They reflected on their observations of and documentation about this young man during his time in school. Subsequently, after he completed high school, they conducted an interview with him, his mother, and some of the other professionals involved in his formal education. The results of this process give credence to the need to identify and focus with the student on areas that need attention, to differentiate and scaffold student learning using multimodal approaches, and to attend to how the various contexts of the school are engaging each student. These results corroborate much of what has been said in varying ways about MBE throughout this issue. Most importantly, they illustrate just how critical and useful it is to include students in the inquiry process.

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Commentary

How New Research on Learning Is Re-writing How Schools Work and Teachers Teach

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Geoffrey Caine, Caine Learning Center

ABSTRACT

The article introduces the notion of a "meme." A meme is an idea, behavior, or style that spreads from person to person within a culture. In education it acts as a powerful assumption, guiding what is meant by learning and teaching and determines that teaching should include a textbook, teacher-directed lessons, control of student behavior, and testing as proof of "learning." The article explores new challenges to this meme coming from current research emerging out of biology, cognitive psychology, and neuroscience. It suggests that a form of project-based learning is more compatible with how the human brain was designed to make sense of experience.

On one of my trips in Canada I was working with a large group of teachers, exploring our Brain/Mind Learning Principles (Caine, Caine, McClintic, & Klimek, 2009). The purpose of the workshop was to expand everyone's view of the many ways in which human beings learn. At lunchtime I walked around asking particularly new teachers how they felt about the information I was providing. After some hesitation they told me that instead of being excited about how to implement this information when they returned to their classrooms, they were confused and anxious. At the time I felt puzzled. What was happening here?

At the end of the day everyone tried to do his or her best to hide a general sense of frustration. Finally one young teacher stood up and said: "I get it! This makes total sense. You just have to *think* differently."

That young teacher was absolutely correct. My presentation was bumping up against deeply held assumptions about the way that schooling and teaching are defined and are generally done. In essence I was asking teachers to move beyond the approach to teaching that everyone believed in. The Brain/Mind Learning Principles called them to go far beyond direct instruction all too frequently required by the system and tied to success on tests.

In our latest book (Caine & Caine, 2011), we expose this educational paradigm as a "meme." A meme is an organized way of thinking tied to action based on a powerful belief about how the world works, one that is shared by a very large number of individuals. In the case of education it refers to a set of powerful beliefs that are preventing new ideas from taking hold.

For example, let's take the question, "What does it mean to learn in school?" Possibly 90% of adults who are asked this question will insist that success will require a textbook, prescribed content, and teacher-controlled instruction guided by assignments, homework, and tests. When ninety percent of adults identify these without prompting, we are looking at a "meme." Parents expect to see teacher-assigned homework, grades, and tests; unions want to tie teacher time spent in front of the classroom as equal to "learning" provided and money earned; politicians too look at direct instruction tied to teacher action and ultimately to test scores; all based on beliefs about school and what it means to learn.

Similarly, ask students in any class why they are studying what they are studying and after looking at you as though you are a bit mad, they will respond that they are doing it *because their teacher told them* to do it or because they have to do it *in order to pass a test or get a grade*. Their own motivation, enthusiasm, and effort to find unique solutions to personally relevant questions are rarely engaged. (The same incidentally holds true for teachers forced to teach the standards using standardized instruction.) The governing meme keeps everyone from questioning what is being done.

Shifting the meme for education begins with a richer understanding of how human beings learn naturally.

Is brain-based learning and even "neuroeducation" really new? The point is that both could be revolutionary if it were not for the old meme. As it is, powerful research continues to be reduced to what everyone understands schools and schooling to look like.

This new research reveals a more complex view of what it means to learn, one that includes the role of emotions and higher order thinking. In more recent times, many of these ideas have been either acknowledged or embraced by cognitive psychology and, even more recently, by neuroscience. These developments have revealed much about every aspect of the functioning of a human being, including motivation.

Many educational scholars have been persuaded by the view of so much agreement across disciplines that each person is a unique integrated living system (Fuster, 2003; Damasio, 2005), something that educators have intuitively understood as they experience their students as complex and "whole" individuals every day in their classrooms. The entire organism—the whole person—interacts with its world. When we see that this sophisticated research is documenting that body, brain, heart, and mind are all involved in learning, the real job of the teacher becomes more visible and the call for alternative ways of teaching becomes more justified. The old meme says little about the many social and emotional issues that confront teachers every day.

Perception/Action

Biologists tell us that every organism (and therefore every one of us) has to develop in two basic and interconnected ways that are indispensable aspects of survival and success—of the continuation of life itself. This is the dance of perception and action—a focus that has been emerging slowly from several different perspectives in recent times (Maturana, Varela, & Paolucci, 1998; Thompson, 2007; Noe, 2004; Fuster, 2003). From a biological perspective the human brain and body are made to learn by acting on something. We do it every day and it is as natural as breathing. Additionally, neuroscientist Joaquin Fuster (2003) makes clear how the human cortex is developed on the basis of personally relevant questions or challenges that lead to action and feedback.

Where do we see this happening?

When you see kids working on videogames, you are watching the perception/action cycle in practice. It begins with curiosity about something and a desire to find out more, leads into the need for more information, applying what is being learned, solving a problem and getting feedback. During the cycle they also do a great deal of practice, practice, practice in order to solve small and larger problems and apply solutions that work for them.

These cycles play out continuously in ordinary, everyday experience. They recur over and over throughout life as people test, and either confirm or change, the ways in which they do things. In a general sense, therefore, "natural learning" can be defined as making sense of experience and acquiring what we have called "performance knowledge" (Caine & Caine, 2001, 2011). Performance knowledge is a blend of the capacities to perceive and act appropriately in the real world.

Another example from ordinary life

- Think of the last time you came across a problem that required a decision and action. Let's say that you moved to a new town and decided after settling in to go on a well-deserved vacation but in order to do this you needed to have someone to take care of your pet. This is step one—the problem or dilemma.
- Next you had to formulate a question like, "Who can take care of my dog while I am gone?" This is the second step—the formulation of what E. Goldberg (2001) calls an "actor centered adaptive question." Such questions are personally important and meaningful and contain a challenge.
- Once you formulated a question you had to look up some answers, which is step three—doing some research, finding an expert who knows more than you do. Sometimes experts lead to more questions but ultimately you learn something about who can take care of your pet. Once you find someone you think you can trust, you collect information on availability, additional referrals, and ultimately exchange information with that person and allow him or her to take care of your animal (solve your problem).
- Throughout this process you learn of things you may not have set out to master, such as facts about your neighborhood, who the most helpful neighbors are, where there are other experts available for your pet including a competent vet, food supply store, and so forth.
- Step four is feedback, which happens in an ongoing way as you move through all of these events (in education we call this "formative assessment"). Feedback also happens at the end when you see whether or not your research and your decisions were right—whether in fact you solved your problem (summative assessment).
- What learners come to know in this way cannot only be documented on a test, but it can also be applied in spontaneous ways under multiple circumstances.

So how does all this translate into education and teaching?

This view of learning is most compatible with project-based learning and in fact, legitimizes this approach. It also provides direction for experiential learning, constructivism, applied arts, and sports. Any approach to teaching that continually includes:

- Genuine student-generated questions
- The ability to pursue their need to know
- Expansion by linking new experiences and understanding to what learners already know
- An opportunity to create something new
- A challenging learning environment
- Both formative and summative feedback

We (Caine & Caine, 2011) call our own version of natural learning that relies on perception/action the "Guided Experience Approach." It is more formally presented and aligned with the research I have mentioned in this article. It includes the following steps and requires an environment of what we call "Relaxed Alertness" (Caine, Caine, McClintic, & Klimek, 2009).

The Guided Experience Approach (GEA)

1. *The GEA begins with a Multisensory Immersive Experience*. This is a direct, real-world experience that represents students' preliminary exposure to a new subject or material to be explored.
2. *Sensory Processing*. This expands awareness of the details and previous experience and triggers greater interest.
   Actor-(Student)Centered Adaptive Questions. These are based on authentic student interests and may emerge out of their own lives in some way.
3. *Planning, Organizing, and Doing Research and Skill Development*.
   This begins the real inquiry into the topic. It combines student research, collective and individual inquiry, teacher-led sessions, explanations, and direct instruction on occasion. Skill development is incorporated, as students read, write, research, or pursue deeper understanding and do more processing.
4. *Creating a Product That Requires Use of New Learning*. This is where new skills and new understanding are applied. At the core is practical application that both enhances accuracy and demonstrates what has been understood and mastered.
5. *Formative and Summative Assessments Handled With Ongoing Active Processing*. Active Processing is essential and nonnegotiable.

Throughout the entire process of student-driven learning, the teacher, fellow students, and other experts continually challenge student thinking, expressed assumptions, mastery of concepts, and accuracy.

6. *Formal Action and Feedback*. Final products are essential to this process. Public demonstrations, presentations, models, or documentations of all kinds take place. Attention is paid to issues ranging from the appropriate use of vocabulary to the ability to answer spontaneous questions ranging from an expert to novice level. Assessment is based on performance and one's ability to verbally explain and present what has been learned using appropriate vocabulary and definitions.
7. *Technology*. The Guided Experience Approach calls for technology to be infused throughout. Technology can be used at every stage, ranging from accessing research, communication tools and resources, and includes the creation and presentation of final projects.
8. *Higher order thinking*. Notice also the almost automatic need to include higher order thinking or what is known as executive functions of the human brain. The reason is that in the GEA, there is a need for constant decision making, planning, analyzing, negotiating, and reflecting, both by individuals and collectively (Caine & Caine, 2011).

So what does all this mean?

The emerging biological and psychological foundations for learning, grounded in the essentials of perception and action, suggest that great teaching must be geared towards some form of sophisticated project-based learning. The developing understanding of the dance of perception and action further suggests that there are a set of essential elements for good project-based teaching and learning, which we frame in terms of the Guided Experience Approach (Caine & Caine, 2011). These elements do not need to be sequential but all must be addressed if this more dynamic way of teaching is to include high standards. It seems to us that this view is a powerful umbrella for many, many developments in teaching practices, ranging from self-directed and self-regulated learning to constructivism and service learning. Not everyone will use the same language. But the common patterns will be evident in similar approaches.

This approach to teaching based on natural learning requires many shifts in our collective beliefs about learning, teaching, and "schooling." It will require a fundamental shift in how everyone else sees his or her role and responsibilities. This means that many common understandings tied to the old meme must be unlearned. But ultimately, what we propose makes more sense and appears more useful for those who will be living in a connected, information, and collaboration-driven world.

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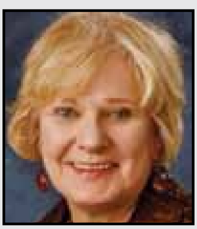

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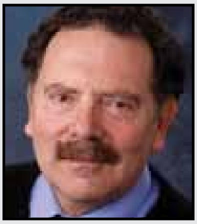

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Commentary

The Need for a Deeper Exploration and Conceptual Understanding: The Critical Role of Creativity and Collaboration in Real-World Learning

R. Keith Sawyer

ABSTRACT

In this interview, author and professor R. Keith Sawyer describes the importance of and interconnections among creativity, collaboration, and the science of learning. He explains that the older paradigm of schooling from 50 years ago where rote learning was predominant is no longer relevant in a knowledge-based society. We now have to prepare students for jobs that require adaptability, flexibility, and creativity. He endorses an approach to education that fosters a deeper conceptual understanding, especially through collaborative creativity. He maintains that true innovation usually comes from a collaboration of individuals rather than a single, brilliant insight. Finally, he comments on recent findings in cognitive neuroscience.

You have written and presented extensively on creativity and the science of learning. How and why did you become interested in these areas?

I became interested in creativity many, many years ago because as a child I was a pianist, and playing piano was a big part of my life. I was first trained as a classical pianist. For about eight years I played traditional European music and then I had an opportunity to join our high school jazz band. I was surprised to discover that the music put before me at the piano had no notes, it just had chord symbols and I was expected to improvise. I went through the experience of having to teach myself how to play piano all over again, and then, being fascinated with the musical interaction that takes place in a jazz ensemble when all of the musicians are improvising and yet they're improvising together. They're being inspired by each other to play better and more creatively than they could have alone. That fascination has stayed with me my entire career, the fascination with group creativity and group improvisation, and that's what I've focused my research on.

Can you explain why you believe creativity and collaboration are key elements of an education?

I think creativity is absolutely critical, perhaps more so today at this point in time than ever in the past. I suppose that we need to think about what school is for and what we expect of our graduates. We are in a knowledge age, it's often been said that we're in a creative age. Particularly in an advanced industrial society, the jobs that do not require creativity tend to be outsourced to low-wage countries or they are automated by advancing computer technology and robots. What people can do—and robots can't do—is creativity. And yet I feel that in many cases our school systems are in a sense still designed for an economy and a society that doesn't exist any more. The schools are very similar to what they were in the 1920s or the 1950s when most jobs did not require so much creativity and people could engage in the same rote, repetitive behaviours and they might stay in the same job for 40 years. That world is gone, and if we continue to educate our students in the same way as 50 or 60 years ago, then we're not preparing them for the 21st century where they will need adaptability, they will need flexibility, they will need creativity, they'll need to adapt to multiple different jobs over the course of their career. That's why I think creativity is particularly important now, more so than ever in the past.

Can you discuss how you believe creativity and collaboration are linked?

In my own research I focus on group creativity and collaborative creativity. It's a bit of a shift from a psychological perspective: when you're trained as a psychologist you're trained to focus on the individual person and the mind of a single individual. If you're thinking about creativity in that framework then you'll naturally think about what goes on in a person's mind when they're being creative or when they're having bright creative insights. When I began to study the creativity literature and then studied the history of invention, it seemed more and more clear to me that real-world creativity—the kind of creativity that actually has an impact on the world, that has a difference in our lives—is almost never the result of one person having a brilliant idea.

I think largely that "big insight" idea is mythical, and in fact, what I found over and over again is that important creative works, or important inventions, always involve lots and lots of ideas, many of them very small ideas, and they all have to come together in a very complex way to result in a successful innovation. I see that over and over again, even inventions from the 19th century, like the invention of the telegraph, the invention of the telephone, a little bit later, the invention of the airplane. In the contemporary era, the invention of something as simple as a new brand of guitar strings, or as complex as a new Broadway musical, a Hollywood movie, a new video game, a new computer software product—all of these things involve immense amounts of collaboration. In a Pixar movie, an animated digital movie, every single frame involves multiple ideas, there's 30 frames a second, so the idea that you can have one person having a great idea, and have that be the full explanation of creativity, I think that's ridiculous. In fact, the full explanation of creativity is always going to involve how did all these different people come together and bring together their own individual ideas, which each in a sense are very small, but when they all come together they can result in something big and powerful. And that's the role of collaboration: it's bringing people's ideas together so that they can result in something that actually will make a difference in the world.

What key things do you think educators should know about the science of learning, and why?

There is an exciting new science of learning that's grown in the past 20 years. In 1991 the *Journal of the Learning Science*s was founded. There was research going on, perhaps in the 10 or 20 years before that, into the science of learning, but it began to coalesce and people who were doing this sort of research began to collaborate with each other, attend the same conferences, and exchange ideas. So we had an incredible growth starting in the 1990s, and after 20 years we know more about how people learn than we ever have in the past. I was the editor of a handbook that captured all of the research in that area. It was published in 2006 by Cambridge University Press; and that captured the previous 15 years of research in that area. It's exciting because it shows how people learn in a deeper, more profound way.

The learning sciences is not so much about how can we help students memorize more effectively so that they can regurgitate the material better on the test. Again, that is sort of an older paradigm of schooling and education: that we need to deliver a lot of information to students and have them memorize it really thoroughly and then take the test to prove that they've memorized it. Then of course what happens is a month after the test they've forgotten everything! I actually ask my students in my college classes … I'm in a very good university so all of these students got straights A's in their classes … then I say, "How many of you have the experience of getting A's on everything in a class and feeling like you really had no idea what it was really about and you really didn't understand it?" And every single one of my students will raise their hand: they get A's without understanding. Now again, it might have been fine in the 1950s or the 1960s when we were in a different era, but that's not going to cut it anymore because to be creative, to engage in adaptive expertise at a high level you need a deeper conceptual understanding of the material. You need to know what it means, you need to be able to think with the concepts; memorizing and regurgitating doesn't prepare you to be creative. The exciting thing about the learning sciences is that it has always been focused on how can we help students get to a deeper conceptual understanding, how can we help them think creatively with material. There is research out there if you want to know what the best way is to memorize stuff better, and I would certainly consider that part of the learning sciences, but the more exciting part is this new way of thinking about education. It's different now: we need to prepare students to be creative. To do that we need them to have a deeper understanding of material and the research is helping us understand how schools and teachers can do that more effectively.

Can you give some suggestions of how educators can foster creativity?

Some of the suggestions would be similar to what I said while answering the last question. The focus should be on deeper conceptual understanding and thinking abilities rather than on memorization of facts or learning how to execute a sort of rote procedure. I think you could apply this to any subject area, regardless of whether you're teaching in history class, in English literature, in mathematics or science—the principles are all the same. For example, memorizing facts, in some cases there are certain things you just need to memorize; you will learn how to multiply more effectively if you memorize the multiplication table—I would grant that absolutely. But ultimately that's a basis for what we really want, which is for people, students to understand the underlying model of what it means.

For example, in seventh grade, eighth grade mathematics class is typically a time when students are learning about fractions, decimals, and percentages. With fractions they may learn how to…they are being taught how to multiply fractions, how to divide fractions, how to find the least common denominator. The way math is taught typically is that they are taught a rigid procedure that gets them to the answer.

Then they are given a worksheet or they do maybe 30 problems—you're multiplying fractions, 30 different fractions. And then you get a quiz and in the quiz they know what the procedure is to multiply fractions. That's exactly the opposite of what I think we need to teach students to be creative, because creativity comes from having that understanding of the underlying model, the deeper concepts that unify the idea. I've had the experience with students learning how to multiply fractions really well but if you ask them questions in a different sort of way you realize that they really don't understand what a fraction is. They can't make the connection between a fraction and a percentage, for example. They don't know that one fourth is the same thing as 25%—and these are students that get A's; but they're not getting the deeper conceptual understanding. We know from creativity research that's what prepares you to be creative. It's that deeper conceptual understanding; it's having the representation of the underlying model. I would say for teachers, in all cases, try to figure out what is that deeper understanding of the material I'm trying to teach, and how can I help students develop that deeper understanding.

What would you suggest to educators to help foster collaboration?

That's a tricky question because there's all sorts of research that shows that students don't naturally know how to collaborate effectively. I think educators and education researchers for decades now have believed in the power of putting students in groups to work together, but it doesn't always work. If you have ten or eleven year-olds or twelve year-olds, they don't naturally know how to collaborate effectively for most effective learning. I think it's the responsibility of teachers to help scaffold these students in what it means to engage in an effective collaboration. It's tricky, they're ten year-olds, they're eleven year-olds, they have all sorts of things going on in their lives, they have social relationships outside of the learning environment, they may be friends, they might not be friends. It requires a lot of effort on the part of teachers. You have to emphasize that learning is a shared endeavour; that it's our joint responsibility to work toward an understanding of the material.

There's sort of broad norms we need to establish in a classroom. And then there are more specific things: the types of questions that you would hope your students would ask in a collaborative group, the types of answers they would provide. We have decades of research showing that in a collaborative group the students are asking, "What answers did you get for this question?" and the other student says, "I got 3.5." That sort of interaction is not helpful; it does not contribute very much to learning. So basically you're wasting the potential of the collaborative group. In contrast, when the groups are contributing more effectively to learning, it's when the students ask each other more exploratory questions, more open-ended questions … and the answers tend to be more about concepts and models, tied into some of my answers to the previous questions. These are things that are very difficult for students to learn how to do now but teachers, I think, could be aware, or need to be aware, of this research; you're circulating among the groups, you're listening to students, and it could help if you could develop exercises for the groups which support the students and guide them gently towards asking a different sort of question of each other and engaging in a more exploratory, more conceptually based type of discussion when they're in the group. A group that is focused on getting the right answer and "What did you get?"—that's a waste of collaboration; you're not going to get any benefit from that. It has to be a deeper exploration of the fundamental material that we're trying to master in this particular activity.

Last year we had the pleasure of hearing you speak and you described an example of creativity, collaboration, and innovation about the Monopoly game invention. Could you tell us about that?

The story of how *Monopoly* was created is a wonderful story because we have a certain belief about how these things happen. The official story from the Parker Brothers Company, the game company, when *Monopoly* was released in 1934 or 1935 … an incredible success, it was selling faster than any board game had ever sold before. Newspaper reporters actually wanted to write stories about the phenomenon, the *Monopoly* phenomenon … so they were calling Parker Brothers up, "we'd like to interview the inventor of *Monopoly*." They put the reporters in touch with this man, Charles Darrow, who had the patent for the *Monopoly* game, and he told the story about how he was sitting in his basement and sort of had this flash of insight to develop this board game where people would buy and sell real estate. Well, it turns out that it was a complete lie, that in fact Charles Darrow essentially just copied a game that was being played among various communities up and down the east coast of the United States and in the mid-west primarily among Quakers, the Quaker religious community, and for about 30 years they had been making their own handmade copies of this game they called the *Landlord's Game*, which the first known copy of is from 1904. Each city, when you're making a copy for your own family, named all the space names on the board after neighborhoods and streets in your town. So, wherever you found a copy of this game it would be different; it would represent your own city. Charles Darrow happened to have some friends in Atlantic City, New Jersey, which is where he first encountered this game and then he copied it and fraudulently obtained a patent. And all the streets, by the way, on the Monopoly Game are streets from Atlantic City, New Jersey, but purely by historical accident.

The reason why I like the story is because it shows how often innovation, even though we like to think of it as the flash of insight of a solitary individual, in fact this story is representative of how it more likely happened, that it takes a long time, there are contributions from a lot of different people over this 30-year time frame. You have a lot of different variations: every city has a different version of *Monopoly* or the *Landlord's Game*, and everybody has slightly different rules. This is the nature of innovation. It's almost like a kind of evolution where it is not guided and there's no plan really but people try out new things and new ways and some of them survive, and some of them don't survive. After this 30-year process even with a successful board game but not *because* of one person's brilliant insight, *because* of the creative power of collaboration kind of stretched out over time. I call it the "collaborative web" because it represents the way that networks and relationships bring people together so that they can more effectively exchange their own creative ideas so that they'll come together and build together toward something more powerful and more effective.

You also talked about brainstorming and some of the misconceptions about brainstorming. Would you discuss that a little bit for us?

Brainstorming is a very widespread and popular technique. It tends to refer to different things. Sometimes when people say "brainstorming" they just mean, "let's get together and talk about this." But, originally brainstorming was coined by an advertising executive named Alex Osborn—I think it was way back in the 1930s, the 1940s. He had four basic principles: that you should be wild and crazy, that you should go for a large quantity of ideas, don't worry about being critical about them, don't worry about how good they are, just go for the volume and try to build off of other people's ideas. A lot of people when they do brainstorming, say it's in a business setting, that's what they'll do: they'll get together and they'll throw out ideas. The interesting thing is as long ago as the 1950s when psychologists first did an experiment on this, they find that if you take four people and put them in a brainstorming group and you count how many ideas they generate in 30 minutes, and then you take four people and have them all work alone for 30 minutes, following the same guidelines (i.e., volume and quantity) and then you pool their four lists at the end of 30 minutes: they generate *way more* ideas than the four people that were face to face doing brainstorming—typically twice as many ideas. That finding is sobering. I guess the implication is that if you really want a large amount of ideas, don't put people together in a room; let them generate their lists separately. That's the surprising finding … it doesn't seem to work as advertised, but once you know the research then you can be more strategic about how you use brainstorming. You could have people generate lists of ideas in their own office and then bring them together and they come to the room with their list of ideas … and then you can take advantage of the real power of collaboration to engage in what I think of is sort of an improvisational flow, a conversation where surprising new ideas can emerge. So don't use the brainstorming group simply to generate long lists of ideas—use the brainstorming group after everybody has already come up with lists of ideas and then try to take those and combine them in some way … build on those to result in something surprisingly new that no one had thought of on their own.

Learning about the brain and how it works has become very, very popular. In fact, that's what this issue is about. Do you have any suggestions for educators about how to use this research effectively?

I recently did a review of cognitive neuroscience studies of creativity. There hadn't been such a review of the literature. An increasing number of people have been doing brain scanning where they generate three-dimensional brain images of people while they're engaged in tasks that seem to involve some creativity. It has to be a task that you can do over and over again and it has to be a task that anyone can do. So you're not asking people to compose Beethoven's 6th Symphony while they're in the brain scanner, but you're asking them to do something like, "here are three related words and try to think of a fourth word that's related to these three words."

Psychologists believe that that involves some of the same basic cognitive or mental processes that may underlie creative behavior. That's the kind of experimental paradigm you're using … you have people engaged in these tasks which seem to involve some component of creativity but it's not really like Steve Jobs coming up with the iPhone or something like that that's going to be impossible to study in a sort of rigorous experimental way. These are the studies … there's been an increasing number of them. The interesting thing to me is that what you find is that creativity—or these tasks that are somehow perhaps related to creativity—they're not really located in a specific brain region—they're spread out all over the brain. A lot of the brain is active when you're engaged in these sorts of creative activities or creative mental processes. In some cases, one small region of the brain might be slightly more active, or another region might be slightly more active, but it varies quite a bit and the conclusion I take from that is this: you need the entire brain working in concert to engage in creativity. We know pretty conclusively now that it's a complete myth that creativity is in the right brain, and we've known that before from other methodologies but it's even more convincing now that we have this brain-imaging technology available. It's absolutely not the case that these creative activities are in the right brain or that some people turn out to be more "right brained" than others. It's sort of maybe a conversational shorthand we use for certain personality types but it has no basis in brain reality.

R. Keith Sawyer, a professor of psychology and education at Washington University in St. Louis, studies creativity, learning, and collaboration. He has a computer science degree from MIT as well as an M.A. and PhD in psychology from the University of Chicago. He has been a jazz pianist for over 30 years, and spent several years playing piano with Chicago improv theater groups. Dr. Sawyer has published ten books and over 60 scientific articles. A popular speaker, he lectures to corporations, associations, and universities around the world on creativity and innovation. He is a participant in the Davos World Economic Forum.

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Commentary

Mind, Brain, and Education: The Impact of Educational Neuroscience on the Science of Teaching

David A. Sousa

ABSTRACT

Researchers have now acquired so much information about how the brain learns that a new academic discipline has been born, called "educational neuroscience" or "mind, brain, and education science." This field explores how research findings from neuroscience, education, and psychology can inform our understandings about teaching and learning, and whether they have implications for educational practice. This interdisciplinary approach ensures that recommendations for applying these findings to instructional practices have a foundation in solid scientific research. It also ensures that teachers are working smarter, not harder. This article discusses some of those exciting applications.

I will never forget a visit I once made to a geometry class in an urban high school. The teacher—let's call her Mrs. Green—was expecting me and, after a brief greeting, she turned to the students and said, "Everybody up. Follow me." She grabbed a boom box as she went out the door, leaving the students somewhat puzzled. Like the Pied Piper, Mrs. Green led the class down to a closed-off section of the gymnasium. Portions of the floor were marked with different lengths of masking tape that formed triangles. Mrs. Green divided the class into several groups, and asked them to measure the lengths of the tape by pacing them out while they clapped to the lively music coming from the boom box. After several trials, she asked them to discuss their measurements and determine if they could see any common relationship. In just 40 productive and engaging minutes, Mrs. Green had helped these students teach themselves that, in a triangle, $a^2 + b^2 = c^2$. Might this lesson have gone differently if everyone had stayed in the classroom and Mrs. Green said, "Everyone open your mathematics books to page 57. Today, I am going to teach you the Pythagorean Theorem."? No doubt.

In a conversation later in the day, Mrs. Green told me, "I cannot teach mathematics today the way I did just five years ago. These kids' brains learn differently, and I have to adjust my teaching strategies if I have any hope of being successful." She recognized that today's students come to school with different expectations, with a desire to participate in their learning, and with the recognition that school is just one—and certainly not the only—source of information. Her comments were also a recognition that research in cognitive neuroscience is providing exciting new insights into how the brain develops and learns. Because teachers are what I call "brain changers," they realize that the more they know about how the brain learns, the more likely they are to design creative and interactive lessons like Mrs. Green's, and to be more successful at helping their students achieve and succeed.

In the past two decades, researchers have acquired so much information about how the brain learns that a new academic discipline has been born. Called *educational neuroscience* or *mind, brain, and education science*, this fledgling field explores how research findings from neuroscience, education, and psychology can inform our understandings about teaching and learning, and whether they have implications for educational practice. These implications do not represent an "in-the-box program" or the "strategy du jour" that teachers sometimes view with a wary eye. Rather, the goal of educational neuroscience is to reflect on this research and decide whether it should have an impact on educational practices. This interdisciplinary approach ensures that recommendations for teaching practices have a foundation in solid scientific research. It also ensures that teachers are working smarter, not harder.

As research continues to provide a deeper understanding of the workings of the human brain, educators should be excited yet cautious about how they apply these findings to practice. There are critics who believe that educators should not be using brain research at this time in schools and classrooms because it will be years before this research has any application to educational practice. Others fear that unsubstantiated claims are being made, usually referred to as "neuromyths," and that educators are not sufficiently trained to tell scientific fact from hype. They often refer, for example, to the notion that students can be just "left-brained" or "right-brained," or that we only use about 15 percent of our brain. Although the concerns are understandable, if outdated, they should not prevent educators from learning what they need to know to decide whether research findings have application to their practice. Furthermore, many educators have now become very aware of the neuromyths, so it is time for the critics to move on.

Some Important Findings

For those who wonder how recent discoveries about the brain can affect teaching and learning, here are a few of the research findings and their implications:

- **Reaffirmed that the human brain continually reorganizes itself on the basis of input**. This process, called *neuroplasticity*, continues throughout our life, but is exceptionally rapid in the early years.
  Implication: The experiences the young brain has in the home and at school help shape the neural circuits that will determine how and what that brain learns in school and later in life.
- **Startled the scientific world with evidence that neurons in the brain *do* regenerate, a process called neurogenesis** (Deng, Aimone, & Gage, 2010).
  Implication: Regenerating neurons enhance learning and memory. It seems that physical exercise, in part, stimulates neurogenesis. Yet time for recess and play is paradoxically being curtailed in many elementary schools to provide more study time for high-stakes testing. Does this make sense? We should ensure that students get adequate exercise every day to keep the brain primed with fuel, alert, and ready to learn.
- **Challenged the notion that the brain can multitask**. The brain can focus on only one task at a time. What is mistakenly called "multitasking" is really alternate tasking, that is, the brain shifting its attention from one task to a second task, and then back to the first one.
  Implication: Each shift of the brain's attention requires increased mental effort and incurs a loss of information in working memory of the first task. In effect, the individual ends up doing two tasks poorly rather than one task well. Although using a variety of strategies in the classroom keeps students engaged, the shift from one activity to another should not be done before the first task is adequately learned.
- **Revealed more about how the brain acquires a second language**. This research dispels the myth that young students (less than 12 years old) learning a second language causes interference with the learning of their first language (Kovelman, Baker, & Petitto, 2008). In reality, the reverse is true.

Implication: Learning two languages simultaneously is no problem for the young brain's language processing networks, and it helps the learners grasp the deeper structure of languages. Start instruction in a new language as early as possible because learning a new language requires more mental effort and motivation after the age of 12 years.

- **Discovered the brain pathways involved in reading**. Brain scans helped researchers discover that good readers use different neural pathways while reading than struggling readers (Shaywitz, 2003).
  Implication: This research led to the development of scientifically based computer programs, such as *Fast ForWord* and *Earobics*, that dramatically help young children with reading problems. In effect, these programs rewire the young brain of struggling readers (thanks to neuroplasticity) to more closely resemble the neural wiring of good readers.
- **Updated our understandings about the capacity limits of working memory**.
  Implication: Recent studies suggest that the capacity of working memory—that is, the number of items it can hold at any one time—is unexplainably decreasing from about seven items to about five. Consequently, teachers should be presenting fewer items in each lesson and asking students to discuss them in more detail so that they are likely to remember them. In other words, less is more. This is no easy task because the amount of information in school curriculums seems to be constantly increasing. Rather, we should be looking to delete items from the curriculum that are no longer relevant for a student to be successful in today's society, and use that time to delve deeper in those topics that are more meaningful.
- **Shown how emotions affect learning, memory, and recall**. Emotions alert the brain's attention systems, and experiences involving emotions are much more likely to be remembered.
  Implication: Students learn better in schools and classrooms with a positive emotional climate—places where they are respected and where they feel the teachers really want them to succeed. They will also remember more of the curriculum content when it is linked with activities that evoke emotions.
- **Recognized the critical role of movement and exercise in learning and memory**. Researchers have discovered that movement and exercise increase the production of a vital substance called brain-derived neurotrophic factor, or BDNF (Ratey, 2008). This protein supports the survival of existing neurons, encourages the growth of new neurons, and is important for long-term memory formation. Furthermore, movement and exercise improve mood and enhance cognitive processing.

Implication: Students sit too much in classrooms, especially in secondary schools and colleges. They should be up and moving during a lesson, and talking about what they are learning because talk, too, is a very effective memory device.

- **Tracked the growth and development of the teenage brain**.
  Implication: Recognizing that the frontal lobe, or rational part of the teenage brain, takes about 22 to 24 years to fully develop, while the emotional parts of the brain develop in about 10 to 12 years. This significant difference in the maturity of brain regions helps us to better understand the unpredictability of adolescent behavior.

- **Developed a deeper understanding of how circadian cycles affect focus**.
  Implication: Knowing that our ability to focus naturally wanes for 30 to 45 minutes just past the middle of the day helps to explain why teaching and learning can be more difficult during that time. The research suggests that teachers should select instructional strategies that center around student engagement during this period to help maintain focus.

- **Studied the effects of sleep deprivation and stress on learning and memory** (Wilhelm et al., 2011).
  Implication: Many students, especially in high school, come to school sleep deprived. Thanks to the temptations of technology and social media, they are averaging about five to six hours of sleep per night when then really need eight to nine hours. Persistent sleep deprivation triggers stress, and stress causes an increase in blood levels of the hormone cortisol. This hormone reduces one's ability to focus and impairs memory. Educators and parents need to remind students of the importance of getting adequate sleep.

- **Recognized that intelligence and creativity are separate abilities that are not genetically fixed, and that both can be modified by the environment and schooling**.
  Implication: What educators do in schools can actually raise (or lower) a student's intelligence and creativity. The major problems facing our global society (e.g., overpopulation, supplies of adequate food and clean water, demand for energy, and climate change) will require creative solutions. Yet school curriculums do not place enough emphasis on developing creativity in their students. Students learn to be more creative through engagement and the authentic applications of their learning to real-world problems.

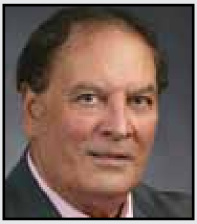
- **Added to our knowledge of how the arts develop the brain.**
  Implication: Research studies are revealing how exposure to the arts can increase one's attention, spatial skills, and creativity. Too often, however, the

arts are the first to suffer in schools when budgets get tight. Although too many people still regard the arts as frill subjects, brain research is showing that they are important contributors to the development of cognitive processing.

- **Highlighted the degree to which a school's social and cultural climates affect teaching and learning.**
  Implication: We are only beginning to realize the impact that students' social needs have on learning. Research findings from the new field of social neuroscience are suggesting that schools need to give much more attention to students' social growth and focus also on the contributions that other cultures can make to teaching and learning.

This is truly an exciting time to be in education, thanks to the new information that educational neuroscience is providing. Several universities in North America and abroad have established dedicated research centers to examine how discoveries in neuroscience can affect educational practice. As a result, educational theory and practice will become much more research-based, similar to the medical model. There is, of course, no panacea that will make teaching and learning a perfect process—and that includes brain research. It is a long leap from making a research finding in a laboratory to the changing of schools and practice because of that finding. We do not want to let the excitement cloud our common sense.

Never has society asked so much of its schools. At the same time, however, never have we known so much about how students learn and what we can do to make that happen successfully. Research in educational neuroscience opens the door in the hopes that educators will experience the joy of seeing more students reach their full potential.



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Dr. Sousa has edited science books and published dozens of articles in leading journals. His books have been published in French, Spanish, Chinese, Arabic, Korean and several other languages.

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Brain, Mind, and the Organization of Knowledge for Effective Recall and Application

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ABSTRACT

Modern neuroscientific research has confirmed and amplified our understanding of how we learn and subsequently recall information from memory. This paper presents a novel model of information networking in memory based on neurocognitive theory. Implications for teaching and learning are discussed—especially ways of enhancing learning of subject matter that promote its effective recall, logical organization in networks, and effective application to thinking, including problem solving and higher-order cognitive processes.

Introduction

A challenge in curriculum design and teaching is to enhance students' ability to organize information in a way that makes it available for efficient recall in response to an appropriate context, and with sufficient generality to be applied in new situations (e.g., critical thinking and problem solving). Increasing emphasis in modern society is placed on enhancing public literacy of major ideas in the disciplines, especially an ability to explain our thoughts and to mobilize arguments to support well-reasoned positions. This is particularly true in the sciences, where knowledge of fundamental scientific principles may be critical in democratic decision-making about technology, management of the environment, and the role of science in society. However, it is also an ideal relevant to the liberal arts disciplines. A liberally educated person should be able to engage in conversation about some major ideas pertinent to cultural, historical, and social domains in a way that is informed and contextually relevant.

We all have probably had the perplexing experience of teaching a major topic in a way that seemed to be immediately effective, only to discover later that some of the students were able to recall and mobilize the information in a thorough and relevant way relative to the context we provided (e.g., a discussion topic, test item, etcetera), while other students seemed unable to recall much of anything, or only fragmented aspects. Why do some learning experiences yield relatively lasting effective organization of knowledge in memory, while others at least for some students appear to yield partial or fleeting recall? There is no solitary or simple explanation for these individual differences in knowledge recall and its application, nor is there a foolproof prescription for teaching that will improve performance. However, a recent line of research is explored in this paper that addresses these issues within a perspective of some current knowledge of the interrelationships of brain, mind, and organization of information in memory, especially focusing on the role of knowledge networks in memory and their dynamic mobilization and application within particular contexts.

A knowledge network in memory is defined generally as the organization of meaningful information within a multi-relational logical framework in a way that permits effective internal reflection and public communication. More specifically, the purpose of this paper is to explore some modern evidence on how we organize and encode information in memory, and how the brain functions to mediate recall and organization of information in response to contextual cues that occasion relevant knowledge recall and its application. Neuroscientific research on how we think and reason is growing exponentially. Only sufficient information about brain structure and function is presented as pertinent to the focus of this paper, and largely in a descriptive format. Practical applications to teaching and learning are emphasized.

Memory, Remembering, and Knowing

As background, it is important to distinguish at the outset between three cognitive functions: (1) Memory, (2) Remembering, and (3) Knowing. Memory is a *state of mind*—a store of potentially retrievable information that has been encoded in a sufficiently stable way to be accessed at a later time. Remembering is a *mental process* of actively mobilizing and reconstructing stored information in a way that makes it accessible for recall relative to a set of contextual cues. Knowing is a *conscious disposition* of organizing information in such a way that it represents a coherent exposition—one that is meaningful to the person who assembles it and capable of being shared with others. For example, in contrast to meaningful remembering, experimental psychologists have utilized nonsense syllables (strings of a few alphabet letters that have little or no possible resemblance to words) as a way of studying memory. The nonsense syllables are intended to be memorized and recalled as a way of examining "pure memory functions," without the contamination of prior knowledge. We could certainly say that the nonsense syllables were stored in memory and that they can be remembered. It would not be appropriate to state that we "know them." They are not meaningful constructs of knowledge.

The Roles of Working Memory and Long-Term Memory

We also need to clarify the difference between "short-term memory" (also known as "working memory" in modern usage) and "long-term memory." Working memory mobilizes information from long-term memory to make it accessible to be "worked with." That is, to actively organize information, interrelate it, or otherwise prepare it for a purpose: e.g., application to a task, problem solving, communication, or by internal reflection to enlarge our long-term memory (e.g., Gathercole & Alloway, 2008; Thorne, 2006). Long-term memory is the information we have committed to long-term storage for retrieval at a later time. Working memory is dynamic and typically of short duration (seconds to minutes). Long-term memory is more stable and can persist for a lifetime. For example, suppose someone asks us to recommend a student who would be a good candidate for an academically gifted learning experience. Assuming that we have stored some fundamental information about most of our students, we probably would begin to mobilize and review in working memory as many visual and semantic (verbal) sources of information about students that are accessible from long-term memory. Implicitly, or more explicitly, we may begin to apply some criteria for assessing the academically gifted and begin to assemble a list of students who we conclude meet the criteria. The process of accessing long-term memory, mobilizing information, and reflectively processing it to reach a goal is accomplished in working memory—a dynamic state of mind.

Sufficient modern scientific evidence has been gathered to explain basically where and how these two forms of memory occur in our brains (see Figure 1 below).

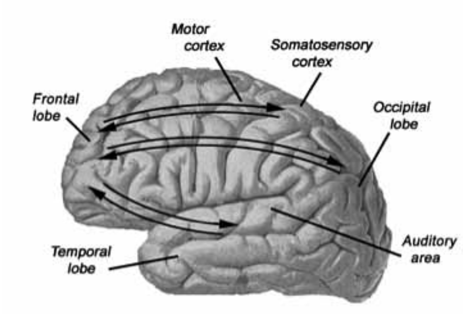

Fig. 1: Human cerebral cortex[1]

We will avoid details of some current theoretical controversies (e.g., Jonides et al., 2008), and focus on consensus interpretations. There is good evidence from neuro-imaging (e.g., MRI) and other brain monitoring techniques that much of the dynamic process of organizing and reflectively thinking about information in working memory is mediated by the frontal lobes (immediately behind our forehead). The frontal lobes, however, are reciprocally connected (forward and backward) by nerve fibers to other parts of the brain (e.g., Figure 1). These include the back of the brain (occipital lobe) where visual images are perceived and stored in memory, the temporal lobes (immediately inside both sides of the skull, opposite the temples behind the eyes) where verbal and conceptual knowledge is partially stored, and the somatosensory cortex (at the top of the brain posterior to the frontal lobes) where sensations of touch and body sensations are located. There are other areas of the cortex, also interconnected with the frontal lobes, where auditory percepts are stored (auditory cortex). The nerve fiber interconnections permit the frontal lobes to access information stored as memories within each of these brain centers. The frontal lobes also exert organizational control over the access and processing of stored information. One of the significant control (executive) functions of the frontal lobes is focal attention. That is, the frontal lobes have been shown to be active when we localize information in memory for specific attention. For example, if we were asked to recall a visual image of the map of North America, we likely would mobilize a general mental image of the overall geography of North America, especially major features of continental boundaries surrounding Canada and the United States, but initially with less focus on details. With intent, however, we can specifically recall details, such as focusing in on the Great Lakes—the details varying depending on our familiarity with their geography.

This capacity to voluntarily focus on specific details, versus general recall of visual information, is mediated by frontal lobe activity through nerve tracts projecting from the frontal lobes back toward the visual cortex. During recall of visual information in the occipital lobe, visual memories are reactivated in the same regions where they were initially perceived. The particular images recalled and their focal detail is controlled by impulses from the frontal lobes transmitted through the nerve fibers projecting back to the occipital lobe. There are other major nerve tracts interconnecting many parts of the brain. These rich arrays of interlinking nerve tracts, among other functions, account for the holistic way that the brain coordinates information processing. In addition to these important linkages, the frontal lobes are also interconnected with a deeper region of the brain known as the limbic system. It has multiple roles. One is to help us consolidate new information to be stored in long-term memory. Another area of the limbic system mediates our emotional or affective responses. Hence, the frontal lobe can access and partially moderate our emotional sensations during information processing. We will refer to this as affective functions. We can now assemble an educationally relevant theoretical model of how we dynamically organize and interrelate information in memory to enhance the networking of information during recall and its application.

A "Contextual-Label-Pointer" (CLP) Model of Information Networking in Memory

Human brain functions are complex, diversified and highly adaptable, especially with respect to information processing and cognitive representations of experience (e.g., Anderson, 2009b; Holistic-educator, n.d.). The following theoretical discussion is not intended to be a general theory of cognition, rather it is a theoretical model that may have practical value in education, especially as a novel way of understanding how learners organize and recall networks of information in memory.

Returning to our previously cited example of recalling a visual image of the map of North America, assume that we were asked to describe our knowledge of the Great Lakes. If we are a resident of Quebec, Canada, we may well identify Lake Ontario as a starting point and begin a narrative by relating it to the other lakes. However, if we are a resident of Chicago, Lake Michigan may well be the starting point. Not necessarily so, of course, if the context for the request specifically states, "Describe the Great Lakes beginning with the largest one." Lake Superior as the name implies is the largest, and there is a definite order of size relationships: i.e., Superior → Huron → Michigan → Erie → Ontario. According to current neurocognitive theory, we mobilize this information in long-term memory by frontal lobe activity relative to the contextual cues that are provided to us. Within a given context, the frontal lobes also mobilize organizing rules or principles to guide the construction of information in working memory. In this case, the rule is *size relationships*. If we were asked to make a reply based on a different rule, such as which lakes are most closely related to the geographic boundaries of Canada, we would likely create a different answer. Again, context is a major factor in determining how the frontal lobes activate major organizing rules or principles to guide the assembly of information in working memory. In a coherent assembly of information, our response may contain (among other aspects) characteristics of, and relationships among, the recalled entities.

The way we construct relationships among recalled items from memory to be communicated as narrative is particularly the focus of this paper. The sequential arrangement of these multiple relationships is one of the cardinal proxies (evidence) for networking of knowledge in memory. How can we create a model to represent the organization and processing of information during a coherent, interrelated, exposition of recalled information? Fundamentally, the concepts of information *labels* and *pointers* are introduced and more fully explicated below to explain information networking. A hypothetical example is diagrammed in Figure 2.

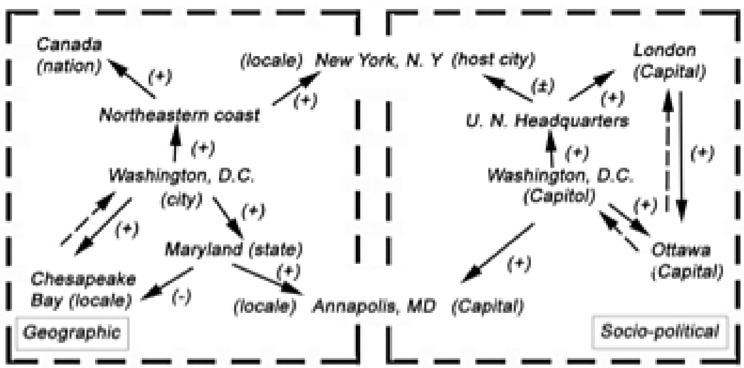

Fig. 2: Interconnected information in networks[2]

When an item of meaningful information is recalled in working memory it may be represented by a "label." A label is a word and/or other symbolic representation (e.g., an iconic visual tag) that is used to represent an entity or category of information in working memory to be assembled as a network. In Figure 2, the verbal label "Washington, D.C." is a placeholder for information that we may have available in memory about the Capitol of the U.S.A. It can represent a specific unit of information, e.g., a declarative sentence "Washington, D.C. is the Capitol of the U.S.A." Or it may represent a category of information, including all of the relevant fundamental information about the city, its geographic locale, culture, history, role in U.S. government, etcetera. In the model, we presume that such labels in working memory also are associated with organizational "pointers." A pointer is a mediating adjunct to a label, previously learned. It is used in working memory to point toward, or to indicate, what other entities of information can be accessed in making logical linkages. The larger the number of pointers available in memory for a given labeled entity, the greater the likelihood that the person can construct a more elaborate and coherently organized network of information. However, the particular pointers mobilized will likely depend on the context. That is, from among the total repertoire of accessible pointers only those that are most relevant to the pertinent contextual cues are likely to be mobilized and used. In Figure 2, there are two examples of how the label of "Washington, D.C." may be recalled within two different contexts: socio-political (right panel) and geographic (left panel). Each arrow represents a pointer that potentially can be used to make a relationship of the idea of "Washington, D.C." with other ideational units. Note that each pointer also has either a (+), (-) or (±). Each indicates the dominant emotional valence or emotional feeling associated with the linkage. A (+) indicates a positive emotional association and (-) a negative connotation. A (±) is used to indicate neutral affect. Moreover, the pointer indicates the most likely direction of association in assembling a narrative sequence. Pointers, however, may be bi-directional (e.g., dashed arrows, Figure 2), indicating that the linkages may likely go either way depending on the logical framework and flow of the narrative being constructed in working memory. The larger the number of bi-directional arrows in the person's repertoire of potential linkages, the more likely the person will construct a richer and more interwoven (inter-linked) set of ideas in her/his assembled network of knowledge.

Working memory is limited in capacity, and labels that represent categories of information are more likely to provide efficiency in organizing and interrelating information in working memory compared to labels that represent only limited information. During the assembly process, the pointers are the potential linkages that can be selected to create a networked set of ideas. In the case of the socio-political context, other labeled entities that are connected by pointers from "Washington, D.C." represent particular subsets of information that can be recalled and in a particular sequence. Note that the other labels in the socio-political context have modifiers (in parentheses) to indicate the contextual category that is relevant to the socio-political perspective, such as (national capitol), etcetera. By comparison, the entities in the geographic contextual field have modifiers that are relevant to geographic concepts (locale, city, etcetera). Two labeled entities (bearing appropriate modifiers for each context) are convergent, that is, accessible within both contexts. They are the labels for the cities of New York and Annapolis (spanning both contextual fields). Note, however, the modifier in parentheses for each one is different depending on the context.

Examining the network of labels and pointers, it is possible to imagine how the organization of the information would unfold when communicated by the person. For example, let's examine the socio-political context. Beginning with the idea of Washington, D.C., using the pointers may lead to the national role of the U.S. in the U.N., located in the host city of New York (NYC), including representatives from London (U.K. capital) and others in the Commonwealth including Ottawa, where officials are in communication with London, etcetera. The reciprocal dashed arrow indicates a possible recall that Ottawa in North America would likely be in communication with Washington, D.C., located in Maryland, and that the U.S. government also must have some political linkages to the state capital (Annapolis). The location of the labels for NYC and Annapolis, at the boundaries between the two contexts, indicates that these ideational units can act as bridges between the two contexts. This example of coherent and cross-connected discourse contrasts with communications where there is less evidence of inter-linked narrative. For example, some students orally, or in writing, seem to recall information largely as a stream of unconnected declarative sentences. Such sequential, non-networked, narrative is often marked by discontinuous logical connectives and little evidence of a coherent overall perspective. Such narrative is categorized here as having low network organization. We will not comment on the affective valence markers for now, but merely point out that the (-) marker on the link to the Chesapeake Bay may indicate, for example, a concern about pollution of the Bay. The ambiguous marker (±) for the link from U.N. to NYC may simply indicate that this relationship has no strong emotional valence. These are revisited later.

Information organized in thought can be holistic and multidimensional (at least initially). However, when assembled for communication, it must be arranged in a serial way due to the sequential structure of language. Thus, the available pointers we mobilize become of particular importance in determining the likely linkages that are used in actively composing narrative. Moreover, in some cases the available pointers place constraints on how the sequence can be organized. If there are few available pointers, the options for organizing a coherent cross-linked sequence of statements may be minimal. Therefore, we see once again the importance of having multiple meaningful pointers associated with each labeled category in memory. The richer the array of pointers associated with each label, and those to which they point, the more likely the person can mobilize a creative, coherent, and thoroughly integrated communication.

Summary of the CLP Model

In sum, the CLP model assumes that working memory, associated with the frontal lobes, is largely responsible for the voluntary recall and organization of information from long-term memory (in addition to any new communicated information). The perceived context, that occasions the recall, establishes the organizational rule or principle in working memory used to access and organize relevant information. Because there are reciprocal cross-linking nerve tracts between the frontal lobes and regions of the cortex where memories are stored, the frontal lobe not only accesses the stored information, but also can control the attentional focus. Thus, the frontal lobes have executive control over what is recalled and the degree of detail. During organization of the recalled content, information with clearly identified labels can be processed most efficiently. This is due to the limited capacity of working memory. The more information units that are "chunked" or grouped under clearly accessible representative labels, the more likely they can be processed rapidly and effectively in working memory. Labeled categories theoretically bear pointers that indicate the variety of other labeled ideational entities that can be organizationally linked with each one during construction on information networks in memory. The more varied and numerous the pointers associated with each labeled category, the more likely that the individual will be able to create a richly coherent and interconnected narrative. The fewer pointers available for each labeled category, the less potential for making richly interconnected representations of the recalled information. By definition, knowledge is the meaningful recall of information, assembled in some organized way. The larger the number of interrelationships among the units of information organized in memory, the more likely the individual will have multiple ways of accessing and applying the information in a meaningful way. Hence, the more likely he or she will be able to think about it constructively and creatively.

Applications to Teaching and Learning

A considerable amount of published evidence indicates that students who organize information with multiple interrelationships during recall are more academically successful. This includes more accurate and complete recall of learned material (e.g., Anderson, 2009a; Anderson & Contino, 2010; Dhindsa et al., 2011; Tsai, 2003), evidence of higher level conceptualization and thinking during recall (Bischoff & Anderson, 2001), and enhanced skill in applying knowledge in analytical tasks such as critical thinking and analysis of data (Anderson, 2009a; Bischoff, 1999; Tsai, 2003). The research methodology is based on a coding scheme that is used to analyze recorded oral or written narrative. The flow of the discourse is analyzed for evidence of recursive relational references to content that the student previously introduced in the stream of narrative. The analysis method is known as flow map analysis. For research purposes, recall is elicited using a carefully described protocol where the context is clearly presented (e.g., Anderson, 2009a).

The CLP Theory in Practical Perspective

According to the CLP theory, there are several major considerations that curriculum designers and teachers need to keep in mind to enhance students' ability to organize and encode information in memory in such a way as to facilitate its efficient multi-relational (networked) recall. The use of a clearly defined context to situate the initial learning is of seminal importance. Context can be established by using a variety of methods. Anchored instruction (e.g., Bransford et al., 1990; NASA, n.d.) that introduces the topic in a clearly organized, episodic (everyday) example can be very effective. A current social issues topic, a problem in environmental pollution, a recent news event that can be video-presented to the class, or an example of an applied scientific accomplishment, are examples from various disciplines that can act as the contextual situation as relevant to the topic of the lesson. It is very important that the context is sufficiently generalized to facilitate mobilization later in a variety of relevant circumstances, including topics of current events and social discourse. Once the situation is well defined as much as possible, subsequent learning activities should be organized to continuously address the context as a theme, thus sparing excessive demand on working memory. Other means include using a visual organizing display. This may include a diagram of suitable generality, but not overly detailed, that otherwise may tax working memory. Student small-group activities that involve making organizing visual maps (such as network diagrams, charts, etcetera) may establish a concrete referent that can be used as a context for organizing information in memory as the lesson unfolds. More on this at a later point.

Given the limited capacity of working memory, it is important that the contextual theme is revisited as the class experience progresses. The context initially presented is basically a guide or map of "where we are going." Subsequently, to enhance effective contextual binding of new information, it is important to help the learners understand "where we are now" by regularly relating the new information to the initial contextual organizing device. Furthermore, a clear plan is important to identify the major categories of ideas to be learned as the lesson proceeds, and each idea should be identified by an easily remembered topic word or phrase "the label." For example, in a lesson on food webs in ecology, the key ideas may include the major biotic components of the web. These are: primary producers (e.g., green plants), primary consumers, and secondary consumers, etcetera. These terms, properly defined, can serve as labels for the key ideas needed to develop a coherent conception of food webs. Each of these labels, moreover, should be well established with "pointers," the logical linking attributes that relate it to one or more other labeled ideas. A careful plan for a lesson requires some forethought about what are the most important and succinct linking attributes (serving as pointers) that can be carefully presented or elicited from the students as each labeled idea is introduced. Students need to engage actively in discussing the labeled idea and its linking attributes, perhaps by assembling them as the lesson unfolds into network diagrams related to the context for the lesson, or by other organizing diagrams, story lines, etcetera that permit the labeled ideas and their linkers to be effectively instantiated in memory. Again, constant reference to the context is critical as each labeled idea and linkers are introduced.

Returning to our current example from ecology, when the concept of a primary producer (green plants or other photosynthetic organisms) is fully developed, a logical progression is to explore the role of primary producers in sustaining other living things by eliciting examples of organisms that consume plants. It is important to elicit as many linkages as possible within the food chain from primary producers to other predatory organisms, thus increasing the number of possible pointers in memory. The predatory organisms can be labeled as primary consumers, those that feed on primary producers, but also including reciprocal (backward directed) pointers as well. For example, the primary consumers also control the population size of the primary producers by preying on them, thus these backward-directed links (pointers) need to be fully discussed and developed. Forward and backward, reciprocal pointers are significantly important in helping students develop strongly linked knowledge networks. They also provide plasticity in recalling information that allows for multiple relational thinking as students mobilize and organize information for recall in working memory. For example, reconsider our sequential order based on size of the Great Lakes. A very different order would be appropriate from the perspective of economic geography, if for example we were asked to explain the transport of goods and materials by ship from the Canadian Maritimes to the midlands; i.e., Lake Ontario through Lake Erie and thence into Lake Huron with further transport into Lake Superior and ultimately into Lake Michigan. For a coherent and interrelated exposition of information based on both the physical and economic geography of the Great Lakes, a complete set of reciprocal (bidirectional) pointers in memory would be required. While working through the complete sequence of a lesson such as the food web, or one on the Great Lakes, a diagram such as the one illustrated in Figure 2 or 3, can be constructed, either using digital projection applications (e.g., PowerPoint) or of course white boards, or other non-digital media.

Some Recommendations to Remember

The important points to remember are to: (1) present the context continuously as the lesson unfolds, (2) clearly establish the relationship of each labeled idea to the broader context in addition to exploring with the students the particular linking pointers that are associated with each of the labeled ideas, and (3) use some form of visual representation to exhibit the network of ideas as they are unfolding. Multimodal representations, including where possible assembling images or symbols of the linked ideas that the students manipulate and arrange on charts or maps (individually or in small groups), are an important consideration. We know the richer the mode of representation (verbal, visual, psychomotor/manipulative) that the students encode in memory as the lesson unfolds, the more likely that they will subsequently have greater probability of accessing information for recall. The issue of reciprocal relations is of some considerable importance, especially for topics where there is potentially a hierarchical, linear sequential, or other salient ordering pattern. Some students tend to encode the information in a strictly unidirectional way. For example, in hierarchical systems such as social, political, or cultural, some students tend to link information only from the most super-ordinate or antecedent categories toward the more subsumed or subsequent occurring components. This strictly forward linking of ideas limits accessibility in networking of information where multiple and diverse linking of ideas requires multi-directional logical organization. For example, when we analyze the logical flow of ideas in students' narrative using the flow-map technique, students with less networking of information tend to have fewer instances of recursive relational utterances as the narrative unfolds. Because they apparently lack sufficient knowledge of reciprocal relations among ideas, they have difficulty in cross-relating their thoughts as their narrative unfolds. Acquisition of accurate pointers is essential to subsequent correct recall. We all have probably encountered students who for some reason learn information with incorrect linkages, and upon recall embark on an explanation that is clearly "off track" relative to accurate knowledge in the field.

Some Approaches to Applying the CPL Model

A range of devices (such as various mind-mapping techniques) can be used to enhance students' networking of ideas (e.g., Dhindsa et al., 2011; Mind Tools, 2001). We have found, however, that a particular approach of this kind, called web diagrams, can be effective in improving knowledge networking, especially for students who are initially less adept (Anderson & Contino, 2010). Fundamentally, this is a diagram (e.g., Figure 3) constructed by students.

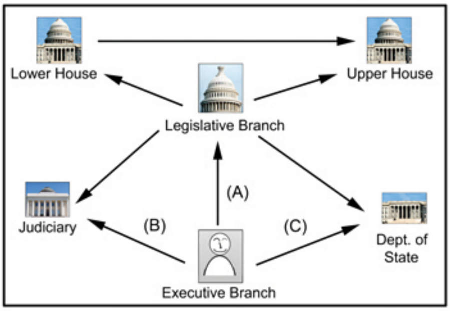

Fig. 3: Web diagram skeletal framework[3]

It includes iconic visual elements and written verbal linking connections among the labeled visual elements. An example of such a diagram for basic government organization and functions is presented as Figure 3. Students are supplied with a relatively large sheet of paper (e.g., 11 x 17 inches) and a set of small paste-on images representing the major conceptual ideas to be interrelated (here some major branches of government). The iconic images are placed on the paper near the periphery in a pattern that permits inserting written linkages, completed thoughts (clauses or sentences), along the connecting arrows. In contrast to some mind-mapping techniques that use single words such as predicates to link the nodes, we encourage students to use completed thoughts, especially including language that expresses bidirectional relations. For example, in Figure 3, the Executive Office link (A) to the legislative branch of government may include statements such as "Executive decision-making, but subject to laws made by the legislators." Similarly, link (B) from the Executive Office to the Judiciary, may include "Separation of powers ensures the Executive office is subjected to the decision of the courts." Or, for the link (C) from the Executive to the Dept. of State, the written statement may be "Executive sets policy within law and in turn is informed of national status." If digital media are available, the students can be given the iconic tabs as small digital images to be pasted into a word-processing or image-processing application to create their web diagrams in digital format. When the web diagram is completed, the student(s) who prepared it individually, or as a small group, should be encouraged to write an essay or make an oral presentation that explicates the multi-relations shown in their web diagram. We have found that students who complete such coherent diagrams, and use them as guides in writing narrative, exhibit higher quality of thinking, more coherent discourse, and increased generality and conceptual level of thought. Thus, in addition to improving their integrated knowledge of a subject, they also may improve their literacy. We have used this successfully with adolescent students, and it very likely can be adapted for younger students.

Keeping Context and Affective Valence Clearly in Mind

Given the important role of the context for initial encoding and also for subsequent organized recall of information, it is important to establish the generalized properties of the context. That is, to help students through discussion or other deep intellectual involvement, to understand what features of the contextual situation especially characterize it, and how other examples of the particular context can be recognized on future occasions. For instance, in a civics class, if a court case is the particular context used to establish the network of ideas, it is important to include at least a final summarizing discussion of what the salient features of the case are. In addition, help students understand what range of other legal situations or social circumstances would also be considered as belonging to this class of phenomena. Unless this refining step is made, students may not be able to mobilize and apply their integrated network knowledge on subsequent occasions where the eliciting cues are from different, but relevant, contextual situations. Broadening the identification of the context, therefore, is a very important consolidating and generalizing step in the learning process.

As promised, we return to a discussion about the emotional valence associated with the pointers. It is important to emphasize the merits of including appropriate opportunities to address affective dimensions in teaching. For example, in the social sciences and humanities, excerpts of poetry, literature, and musical genre of interest to the students can be included to lend additional affective strength to the topics to be encoded in memory. Certainly, moral issues should be considered with adequate opportunity to express rational emotional responses to situations that affect individual or collective well-being in society. This is equally true in sciences, as well as the humanities, where issues of science, technology, and society provide opportunity for moments of reflective critical analysis of the role of science in society, including moral and ethical dimensions of proper and improper uses of science and its applications.

Summary

Modern neuroscience has partially confirmed, and more fully amplified, psychological explanations of how we learn and respond to our environments, especially the role of cognition in perceiving and internally representing experiences. We now know that the frontal lobes are the site of major information processing in working memory, guiding the recall of information from long-term memory to be merged with current incoming information from the environment to dynamically create organized representations of experience. Nerve fiber projections interconnecting the frontal lobes with sensory portions of the brain permit controlled recall of stored information, regulate the focus of attention, and using contextual organizing rules or principles organize the information into a form to be communicated. The kinds of conceptual linkages made, and networking richness, depend on the number and diversity of associated pointers that have been associated with each major idea. The pointers are used to direct the composite linkages among the ideas constructed in working memory. The situational context determines what organizing rules are applied and what pointers are likely to be mobilized in constructing a coherent representation of knowledge to be communicated. Pointers also carry emotional valence, and this can be a useful adjunct to the cognitive meanings associated with the categories and their pointers during learning. Working memory is limited in capacity, so it is important during learning to keep a consistent context in perspective, make clear the kinds and variations of pointers that can be associated with each idea to be learned, and help students to use these cognitive tools to better organize and store information in memory for later coherent recall. Multimodal teaching and learning can facilitate the richness of the context and the variety of pointers in memory. Modern strategies of active, hands-on learning, and teaching (e.g., mind maps and web diagrams) that facilitate networking of ideas during learning can be used to enhance students' preparation to encode memorized meaningful information in a more stable way. Thus, it can be recalled, better organized, and applied more effectively at a later time.

Notes

1. Frontal lobe is a site of working memory and executive control functions. Temporal lobes (left and right) mediate verbal learning and formation of conceptual information, including a region for auditory perception. The occipital lobe is the site for visual perception. Somatosensory cortex receives tactile and body sensory information. The motor cortex, immediately adjacent to the frontal lobes, controls movement. The limbic system mediating formation of long-term memories, and at other sites emotion, lies deep within the brain at the level of the temporal lobes. The bidirectional arrows indicate nerve fibers that link the frontal lobes to the sensory areas of the brain where information is stored as described in the text.

2. A diagram illustrating interconnected information in networks as represented by the CLP model, with labeled information entities (e.g., Washington, D.C.) and others interconnected by arrows representing pointers that are mobilized in memory to mediate making linkages during construction of information networks in working memory. There are two contextual fields, enclosed by dashed lines that occasion the knowledge recall: socio-political (right panel) and geographic (left panel). See text for details.

3. An example of a web diagram skeletal framework for knowledge about basic government organization and functions. The labeled pictorial (iconic) entities and the interconnecting arrows (pointers) are applied as a student might prepare them for the next step of inscribing written clauses or sentences along each arrow describing each of the interrelationships. See text for examples of possible inscribed sentences for the links A, B, and C.

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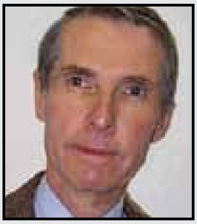

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Your Mind on Music: Muffins, Magic, Mozart, Myth

Jean Emmerson, University of Saskatchewan

ABSTRACT

This article[1] begins with questions that arose during my experiences as a young musician touring with a band. I explore answers to these questions through examining the difference between the mind and the brain and describing selected research on the effects of music on the brain. I then review the literature on the presence and power of music in adolescent and young adult life. Lastly, I apply these findings to learning.

Muffins/Magic

In my younger days I toured as a pianist/vocalist with a new wave band, *Martha and the Muffins*, travelling across Canada and the northern United States singing *Echo Beach*:

> I know it's out of fashion and a trifle uncool
> But I can't help it I'm a romantic fool
> It's a habit of mine to watch the sun go down
> On Echo Beach I watch the sun go down
> From nine to five I have to spend my time at work
> My job is very boring—I'm an office clerk
> The only thing that helps me pass the time away
> Is knowing I'll be back at Echo Beach some day
> On silent summer evenings the sky's alive with lights
> A building in the distance, surrealistic sight
> On Echo Beach waves make the only sound
> On Echo Beach there's not a soul around

Echo Beach, far away in time, Echo Beach far away in time
(Gane, 1980)
Echo Beach 30th Anniversary Version/Martha and the Muffins—YouTube

By day we were on the road or were interviewed by local media. By night we played. Those were magical nights; nights of sound and light, nights of merging with a sea of faces singing along with songs first heard on obscure college radio stations, nights of weaving a spell from a place *far away in time*, far away from the drudgery of a summer job.

I wondered, why is music so potent? What moved our audience to learn the lyrics by heart? What is known about the mind, the brain, and learning that might explain the potency and significance of music?

Mind/Brain

First, to differentiate mind from brain: Russell (2008), a philosopher and futurist, observed that the brain is a physical substance inside the head, whereas the mind is what we know. We experience the mind every moment through our thoughts and feelings; we know we have a brain, but do not sense it. What happens in the brain affects the mind. Thus, the brain is physical matter; the mind is subjective experience. Music affects both.

Zatorre (2003) of the Montreal Neurological Institute at McGill University reported on the correlation of the experience of music in the mind with activity in the brain: "The chills effect is experienced as a very positive emotion and is sometimes described as ecstatic or euphoric by many individuals. Thus it seems to capture one of the most intense aspects of the affective response to music" (p. 11). Zatorre used positron emission tomography (PET) to measure the neural basis for this response. Research participants selected a passage of instrumental music that gave them chills. Once inside the brain scanner, they reported feeling the sensation during 77% of the trials—a fair percentage, Zatorre said, given the lack of comfort of undergoing a PET scan compared to sitting on a sofa at home. Respiration, heart rate, and muscle tension were also measured, and significant increases during the shivers sensation occurred in all three of these variables. At the point of feeling chills, a pattern of activity similar to that found in other brain imaging studies of euphoria or pleasant emotion was present. Simultaneously, a decrease in activity occurred in a portion of the amygdala responsible for fear and negative emotion. Activities necessary for evolution such as eating and reproduction also involve these reward mechanisms, and Zatorre questioned why music recruits the same brain systems.

There are contrary hypotheses. In *This is Your Brain on Music*, Levitin (2007), a music producer and neuroscientist at McGill University in Montreal, quoted Pinker, author and cognitive psychologist, who said that music lacks an evolutionary basis and is merely "auditory cheesecake" (p. 248). Levitin also cited Darwin (1871), who had a different opinion:

> I conclude that musical notes and rhythm were first acquired by the male or female progenitors of mankind for the sake of charming the opposite sex. Thus musical tones became firmly associated with some of the strongest passions an animal is capable of feeling and are consequently used instinctively … (p. 251)

Levitin noted that tribal singing and dancing embody natural selection, since the performers display stamina and good health. He believed that the popularity of rock groups with youth parallels an evolutionary function of song and dance in mating and sexual selection. Perhaps this is why music is so potent. It seems plausible to me, after many nights of playing for frenzied, passionate crowds on the dance floor. Music offered them an opportunity to try on new roles: the lover, the loony, the leaping lizard (operating from his reptilian brain after one too many drinks). Sometimes, people in the audience seemed to idolize us; we were where they wanted to be, in the spotlight, creating a synergy, an indelible moment. Levitin postulated that music not only has an evolutionary basis, but can also affect memory:

> Music's evolutionary origin is established because it is present across all humans … it involves specialized brain structures, including dedicated memory systems that can remain functional when other memory systems fail (when a physical brain system develops across all humans, we assume that it has an evolutionary basis); and it is analogous to music making in other species … (pp. 265–266)

Perhaps these dedicated memory systems explain the ability of the youth on the dance floor to remember our song lyrics. Or perhaps some of these youth had a background in music; there appear to be shared neural areas for music and language processing (Besson, Schön, Moreno, Santos & Magne, 2007). Much current research interest in music is connected to the relationship between music training and increased brain development and plasticity (see, for example, Schlaug, Altenmüller, & Thaut, 2010; Trainor, Shahin, & Roberts, 2009). Studies using magnetic resonance imaging (MRI) have found more developed brain structures in musicians than non-musicians, i.e., the corpus callosum (Schlaug et al., 2010), planum temporale, inferior frontal gyrus, cerebellum, and Heschl gyrus gray matter volume (Besson et al., 2007; Trainor et al., 2009). These studies have stimulated investigations into transfer effects, in which learning in one area reinforces another.

Mozart/Myth

The *Mozart Effect*, a phenomenon based on a University of California study (Rauscher, Shaw & Ky, 1993) has resulted in a common perception that "music makes you smarter" (Demorest & Morrison, 2000, p. 33). In the Rauscher et al. study, students did better on a test of spatial ability after listening to Mozart. Soon, websites promoting music-enhanced learning mushroomed. Parents, eager to boost their children's intelligence, bought *Baby Mozart* CDs. A repeat study two years later with a larger cohort placed students into three groups:

- Group 1: 27 students listened to 10 minutes of Mozart
- Group 2: 26 students listened to 10 minutes of silence
- Group 3: 26 students listened to 10 minutes of minimalist music/spoken word

After listening, the students did 16 exercises on a Stanford Binet IQ spatial subtest, which involved visualizing the designs from drawings of paper that had been folded and cut, much like a schoolchild's paper snowflake. Over the next four days, the students again did the subtest. The results were as follows:

- Group 1: improved from day 1-2 and again from day 2-3
- Group 2: improved from day 2-3
- Group 3: did not improve

The researchers concluded that the *Mozart* group improved due to listening to the music, while the silence group improved due to a normal learning curve. These results were not replicated by other researchers; it was found that if the *silence* group were given any task to do, such as reading a book, it would have similar subtest scores to the music group (Levitin, 2007). Research has since suggested that the *Mozart Effect* was not attributable to Mozart, but to elevated mood and arousal levels promoted by lively music in a major key, which in turn promoted capability on a spatial test (Thompson, Schellenberg, & Husain, 2004). Perhaps the lively *Muffins* music elevated audience mood and arousal levels, promoting lyric learning?

Your Mind on Music

While the Rauscher et al. (1993, 1995) research concerned the short-term benefits of listening to music, other research has focused on the longer-term effects of music training on learning. In a review of quantitative and qualitative educational and psychological studies regarding the effects of music on the personal, social, and intellectual development of children and youth, Hallam (2010) presented strong support for the advantages of active musical engagement, especially in early childhood, on language development, literacy, numeracy, intelligence, creativity, concentration, confidence, sensitivity, social skills, relaxation, and coordination. Adolescents were also found to have gained health, social, and personal development benefits through music.

Music is an important part of life for many adolescents and young adults worldwide. In a study on American adolescents' use of music in their daily lives, Larson (1995) found that many youth used music to help develop their identity: to demarcate separation from parents, establish solidarity and belonging with peers, regulate emotions, and facilitate exploration of possible selves. In the Netherlands, music is central in adolescence—both socially and personally—and peers often share music preferences (Selfhout, Branje, Ter Bogt, & Meeus, 2009). In research on the benefits of music to Finnish adolescents, Saarikallio and Erkkila (2007) provided exploratory and theoretical clarification of the role of music in adolescent mood regulation. They found that music allowed for the release of negativity, provided entertainment, revival, diversion, discharge, sensation, solace, and promoted mental work. In particular, controlling one's feelings and feeling good—or better—were important. "Music seemed to have an outstandingly strong effect on mood improvement: as long as the musical activity was self-selected, it always seemed to make the adolescents feel better and change their mood in a positive direction" (p. 95). Favourite songs and singers seemed to affect the youth most intensely, and they experienced pleasure when singing or playing. Drumming discharged emotions; listening to lyrics helped clarify feelings and thoughts, gain new insights, and comfort youth in times of trouble; and writing their own songs was an effective way to deal with personal issues. In the United Kingdom, group singing was found to increase positive feelings in young adults: self-reported benefits included a sense of well-being, improved breathing, relaxation, social connections, and emotional uplift. One participant's explanation of the benefits of music was, "If your physical side is related to your spiritual side, then it can do only good. Healthy mind, healthy body, etc." (Clift & Hancox, 2001, p. 252).

Music seems to appeal to adolescents because it addresses developmental issues, including establishing emotional independence from parents, creating peer relationships, becoming socially responsible, acquiring new beliefs and values, and facilitating identity development (Tarrant, North, & Hargreaves, 2002). Most people form their tastes in music by late adolescence or early adulthood (North & Hargreaves, 2008). This is partly because our brains are still developing during adolescence, and also because we become less open to experience as we age. During our teens, we experiment with new ideas, sounds, and social groups, and are initiated into adult activities. We often form our musical preferences based on those of our peers, and future music tastes are based on our musical experiences in this critical period. Favourite songs reflect youths' feelings, and many young people seek moral and social guidance in music: apparently the average adolescent listens to 10,500 hours of music between grades 7 and 12 (North & Hargreaves, 2008). These factors show the significance of music for adolescents and young adults.

Music/Learning

Educators can support adolescent learners by incorporating some of the findings from these studies into their teaching practices. Possible strategies include: basing music experiences on adolescents' music preferences, abilities, and needs; developing trust, group identification, and cohesion through cooperative music activities; accommodating individuals of varying ability; using songwriting as a form of self-expression; facilitating group interaction through music; and using music-listening to facilitate stress management (Duerksen & Darrow, 1991). The curriculum could be expanded through activities such as drumming and percussion (perhaps with the assistance of a community drum teacher), analyzing and singing favourite popular songs, and writing songs in small groups. Working with a school counsellor could provide therapeutic support for adolescent learners facing developmental challenges. A team-teaching strategy with a counsellor could model collaborative values and mentorship through lyric writing, music listening, and discussion of favourite songs. Another possibility is the development of student rock bands. A program in the United Kingdom called *Musical Futures* (Green, 2008) experimented with youth forming rock bands in school. Or perhaps existing bands—formed outside of school—could perform in class. Young rock musicians could teach other students basic skills or parts on their instruments. In my youth, a music instructor invited student rock bands to perform and added vocal and band arrangements to their songs. This motivated me to move from playing classical music to rock and jazz, and led to work with the Muffins and other bands.

Muffins and magic, Mozart and myth, music and the mind, bands and the brain. The potency and significance of music for youth can partially be explained through brain imaging results indicating feelings of euphoria and reduced fear and negative emotion while listening to music. Evolutionary theory suggests that the popularity of rock groups with youth corresponds to the function of song and dance in mating and sexual selection. Further, music's evolutionary origin involves specific memory systems that can remain functional when other memory systems fail. Musical experiences in the critical period of adolescence result in the formation of music tastes by early adulthood. Through music, many youth discover social guidance, address developmental issues, express themselves, release emotions, feel increased self-worth and belonging, and find entertainment, diversion, and solace. Based on the literature and on my experience, it is unsurprising that music is so pivotal for youth.

And perhaps it is unsurprising that music is so potent that youth are moved to learn lyrics by heart. The lyrics in *Echo Beach* focus on the romantic, the surreal, where waves make the only sound, and reality becomes bearable. And now, three decades later—as seen in the flashback video clip—*Echo beach* echoes back to yet another reality, far away in time.

Notes

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The Teenage Brain and Technology

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ABSTRACT

The teenage brain is experiencing amazing transformations which set into motion unprecedented academic and emotional growth. As the brain is changing, technology works as a powerful influencer, sculpting and molding the mind. Computer-based instruction, in particular, is impacting the teenage brain as a motivator, tutor, and prolific source of information. Research synthesized from the fields of neuroscience, education, psychology, and technology inform and strengthen pedagogy for teaching secondary students.

Introduction

Technology plays an ever-growing and significant role in our education system; it is embedded into every subject area, at every grade level. The Internet, Smart Boards, computer games, and cell phones reinforce basic skills, promote higher order thinking, and encourage students' motivation. In fact, their use is so pervasive, that it is reported that ninety percent of students in grades six to 12 use computers on a regular basis (Genevalogic Report, 2007). This has changed the way teachers teach and the way students learn. The impact is empiric; the average intelligence of each generation is rising, not only as measured by I.Q. tests, but also by observed behaviors. Researchers speculate that the reason for this advancement is the new technologies embedded in our lives (Sternberg, 1997).

The purpose of this review is to examine technology in the classroom and consider how it interfaces with the processes occurring in the teenage brain. Three questions guide the review, first, what is happening in the teenage brain? Second, how is technology impacting the changes occurring in the teenage brain? Third, which technology-based instructional strategies are compatible with the teenage brain? Practical ideas for teachers are infused.

As a professor and researcher of adolescent development I have authored a number of books on the teenage brain, along with conducting research in public middle schools, adolescent correctional facilities, and secondary schools in developing countries on a Fulbright Scholarship. My ever-present interest in the teenage brain and the plethora of new technology emerging in the classroom piqued my interest and was the impetus for this review.

Prior to delving into the topic, a common understanding of technology terms enhances communication and avoids confusion. E-learning encompasses all forms of electronic teaching and learning, including computer tutorials, simulations, virtual labs, and the Internet (Tavangarian, Leypold, Nölting, & Röser, 2004). Computer-based instruction is more specific and refers to lessons in which computers are the primary method of teaching (Encyclopedia Britannica, 2011). Finally, social networking is associated with relationships and communication fostered through strategies such as websites, discussion forums, and chat rooms.

Teachers are now given the added challenge of being experts in the field of technology, along with their discipline (Anderson, 2004). The wide-ranging use of e-learning tools compels educators to pause and examine their use in relation to the developing teenage brain.

The Teenage Brain

Adolescents are experiencing extensive brain transformations as they move toward cognitive, emotional, and social adulthood. As a result, they are particularly susceptible to outside forces found in the environments of school, home, and recreation. Each new experience interacts and sculpts the brain they will take into adulthood. Of the many external sources interfacing with the teenage brain, technology is prevalent and potent (Galimberti, Bednare, Donato, & Caroni, 2006).

An influential process occurring in the teenage brain involves dendritic branching and synaptic connections. Dendrites are hair-like structures that emerge from neurons when new information is learned; one neuron has between 1,000 and

10,000 dendrites receiving information from other neurons. Each neuron has only one axon which then sends information between neurons. Together, dendrites from one neuron and the axon from another communicate with each other, generating a synaptic connection. Synapses are electrical connections between neurons that aid in information transmission. The production of dendrites and synaptic connections represent knowledge acquisition (Giedd et al., 2009; Paus, Keshavan, & Giedd, 2008). Interestingly, an over-production of dendrites and synaptic connections occur during the teenage years, which creates a unique opportunity for secondary students to learn (Giedd et al., 2009; Paus et al., 2008).

Research indicates there is a relationship between learning and quantity of neural connections. The educational implication is that students who learn a great deal in a subject area grow more neural connections in response. Conversely, neglect of an area inhibits neural connections. For instance, students who dedicate themselves to playing the piano have more neural connections in that module of the brain than those not musically inclined (Le Be & Markram, 2006; Paus et al., 2008). This effect constitutes a strong argument for time on task equating to achievement (Cotton & Wikelund, 1990). However, there is an important caveat to consider: it is the quality of time on task, not simply the time on task that makes the difference in how the brain develops (Evans & Bechtel, 1997).

This period of overproduction of dendrites and synaptic connections in the teenage brain is followed by pruning: a process that operates on the "use it or lose it" principle. Pruning eliminates unnecessary and unused dendrites and synaptic connections. Information that is not recurrently used is subject to elimination. Due to pruning the brain forgets an acquaintance's name or an insignificant date. However, information frequently used, such as a close friend's name and birth date, is deemed important and preserved. The purpose of pruning is to allow trivial data to wither and die, thereby aiding in functional proficiency. The teenage brain experiences extensive pruning, refining and sharpening its capabilities (Paus et al., 2008).

Finally, there is a significant escalation in myelin production, an insulating sheath that coats axons which increase the teenage brain's speed and efficiency. This process occurs developmentally with the frontal lobes in the final phases. Hence, abstract thought, associated with the frontal lobes, only begins to develop during the young teenage years (Drury & Giedd, 2009). As myelination spreads throughout the adolescent brain, an increase in working memory and an ease and competence with learning is experienced. The teenager is developing an adult brain (Giedd, 2010).

Plasticity is a fascinating attribute of the brain; it is the brain's ability to change throughout the lifespan, be it the infant, adult, or teenager. Plasticity involves the brain creating new connections and discarding unimportant ones. In this venture the environment, along with genetics and the behavior of the individual, allow the brain to reorganize neural pathways with new information and experiences. Plasticity has served the human race well as it progressed from agrarianism, to the industrial revolution, into the information age. In each era the brain learned and adapted to new skills in order to meet the environment's ever-changing needs (Costandi, 2010). The brain's ability to reinvent and mold itself is of particular significance during the teenage years. As discussed, the adolescent brain is experiencing unparalleled change, which results in a brain exceptionally receptive to the environment (Giedd et al., 2009).

Another important discovery regarding the teenage brain involves the emotional part of the brain, the amygdala. The teenage brain, still a work in progress, relies on the amygdala to process feelings. This is in contrast to the adult brain which has developed and learned to rely on the frontal lobes, associated with higher order thinking. Consequently, adults are able to make reflective decisions, logically analyze information, and temper the irrational amygdala. The teenage brain, on the other hand, is only beginning the transition from dependence on the amygdala to the frontal lobes. This explains their emotional reactions, misunderstandings, and struggles with abstract thought. Teachers can expect to see a dramatic difference in emotional control between a 14-year-old and an 18-year-old student due to their progress in brain maturation (Killgore & Yurgelun-Todd, 2007).

The evidence from neuroscience is indisputable: the teenage brain is a brain in transition. Clearly, these changes are heavily dependent upon experiences, in which the medium of technology plays an integral part. However, as we learn more about technology and the brain, it is important for educators to keep in mind that instructional technology is dependent upon good teaching pedagogy and content knowledge, the cornerstones of academic achievement (Anderson, 2004).

Computer-Based Instruction

The Internet

The younger generation fearlessly surfs the Internet, browses social networks, downloads tutorials, and scrolls through PDFs in pursuit of its education. The

Internet, in particular, increases the information available in the classroom. It allows students immediate access to research, fast facts, and experts from around the world. No longer must students travel to a library to thumb through paper documents, instead, instantaneous and unprecedented access to a plethora of resources is provided by the Internet (Green & O'Brien, 2002). This amazing accessibility equates to usability; in other words, learning is facilitated by sheer availability. This potentially opens the door for dendritic branching and synaptic connections. As each bit of information is learned the human brain grows and rewires (Hastings, Tanapat, & Gould, 2000).

Neuroscientists confirm the Internet's positive impact on the brain. Individuals who regularly use the Internet have twice the activity in their frontal lobes as those who rarely use the Web. This means the frontal lobes, associated with application, analysis, synthesis, and evaluation, are performing higher order thinking skills (Takahashi et al., 2007). Additionally, surfing the Internet engages multiple areas of the brain, a sign of complex work being done. In fact, searching and learning on the Internet demands more complex work from the brain than reading a book, which was historically the gold standard. Internet use also increases the brain's ability to store and retrieve memories, adjust and change to new information, and improve motor dexterity—all skills valued in the real world (Small, 2008).

Not all the news is good relating to the Internet: neuroscientists have concerns about the reflexive demands of technology. The Internet and computer games are designed for, and compel, perpetual change. This results in snap decision making and multitasking. It is speculated that today's students have fine-tuned these skills to the point of fostering a reduced attention span. This is a significant finding regarding the learning process. If the ability to pay attention is deficient, learning is jeopardized (Cantor, 2009).

It has also been suggested that the younger generation's dependence on the Internet has weakened its social skills. The older generation learned to read facial expressions and body language as a result of face-to-face interactions. The younger generation, nurtured on technology, chooses an artificial means of interaction in social networking. This brings forth concerns that computer use may stunt their social development (Carr, 2010).

Tutorials

E-learning in the classroom is not limited to the Internet; in fact, well-designed computer tutorials represent educational practice at its best. When quality instructional planning is in place, practice is provided, feedback is immediate, and self-pacing is innate. These instructional components are compatible with the teenage brain, and academically support their developmental needs; however, it is important to note that computer tutorials often focus on basic skills (Pitler, Hubbell, Kuhn, & Malenoski, 2007).

Practice has long been identified as an instructional strategy that improves learning (Marzano, Pickering, & Pollack, 2004). Interestingly, longitudinal studies and meta-analysis show that computer tutorials are particularly effective in delivering practice that increases student achievement on standardized tests (Sivin-Kachala & Bialo, 2000). This aligns with what we know about the human brain. When actions are repeated through practice, synaptic connections are preserved and strengthened in the brain, facilitating mastery learning (Salimpoor, Chang, & Vinod, 2010). For instance, mathematics facts that are practiced to the point of automaticity are easily retrieved, allowing the brain to expend energy on higher-level mathematics skills.

Computer tutorials also allow students to progress at their own rate and level, receiving immediate feedback as they work, supporting a student-centered environment (Inan, Lowther, Ross, & Stahl, 2010). Feedback is essential to the brain. When students are told an answer is incorrect, the associated dendrite and synaptic connections begin to wither, while feedback on correct information is strengthened. Additionally, as students receive positive feedback, an indication that learning has occurred, they advance to more difficult material in the tutorial. This structures an ideal curriculum that challenges, but does not frustrate students (Luo & O'Leary, 2005; Marzano et al., 2004).

Games

Highly interactive and goal-oriented computer games are a popular instructional tool in classrooms (Rieber, 2005). In one study by Clark and Ernst (2010), over 90% of the teachers and students advocated using computer games for instruction. The reason for the enthusiastic reaction can be found in dopamine. The neurotransmitter, dopamine, is released in significant amounts during gaming, providing feelings of satisfaction and joy. This prompts student motivation and plays a critical role in the learning process (Koepp et al., 1998).

However, when it comes to academic achievement the reviews are mixed. One of the best-known studies to highlight a concern involved a comparison between Nintendo games and basic paper/pencil mathematics. Counterintuitively, the basic mathematics stimulated more areas of the brain than the gaming did. The academic implication is that the gaming was disturbingly uncomplicated and undemanding of the brain (Kawashima, 2001). Other research concurred, finding that academic achievement did not increase with gaming, even though satisfaction and motivation grew (Kinzie & Joseph, 2008). However, these results are not conclusive, counter findings were found in research done with high school students studying science. Students' science achievement increased when they engaged in academic gaming as opposed to paper and pencil activities (Papastergiou, 2009).

These findings are of particular significance to secondary teachers as many teenagers spend hours gaming on a daily basis, bringing forth the question of how much is too much gaming? Preliminary research by neuroscientists suggests an addictive power in computer games; they ominously resemble addictions to drugs and alcohol. Compulsive game players are much more aroused by the game cues than occasional players. The game becomes a cue to the addictive activity, resulting in excessive amounts of dopamine being released, and finally a craving for the game develops (Duven, Müller, & Wölfling, 2011). Neuroscientists believe the adolescent brain is particularly vulnerable to addictions due to the substantial transformations occurring in their brain (Giedd, 2004). The educational implication for teachers is to be cognizant of appropriate and inappropriate duration of academic gaming in course assignments.

Another issue regarding computer games is the quick responses required for success. Fast-paced decision making promotes impulsivity, a behavior that exists during the game and for a significant time afterward. The reason behind impulsivity is that continued play tends to over-engage the amygdala, the emotional part of the brain, and put the frontal lobes to sleep, creating an unhealthy brain balance. Consequently, the adolescent becomes less able to make reflective, well thought-out decisions. Instead, snap decisions, short attention spans, and high emotion are the behaviors of choice (Mathews et al., 2006).

While violent video games are not allowed in schools, they are played in some homes, indirectly impacting schoolwork. Testosterone levels increase with gaming, agitating the amygdala and increasing the likelihood of explosive outbursts. Research has found that this type of gaming desensitizes players and intensifies aggressive behavior for a significant time after the game has been discontinued (Oxford, Ponzi, & Geary, 2010). Serious concerns surround violent video games, deserving of serious adult control.

Graphic Organizers

Expanding e-learning's potential is the new "normal" in the classroom. Broadening the scope of computers to include complex tasks, problem solving, and decision making activates the frontal lobes, prompting analysis, synthesis, and evaluation, higher order thinking skills (Klopfer, Osterweil, Groff, & Haas, 2009). Computer-based strategies, in the form of simulations, e-labs, and graphic organizers, that challenge, encourage exploration, and provide variety, are capable of meeting these academic demands (Rice, 2007).

Of the various modes of e-learning, graphic organizers are especially adept at promoting higher level thinking skills through compelling visuals (Jonassen, 2002). Educationists found that the visual support of information provided by graphic organizers assist students in scaffolding learning, using logical reasoning skills, and applying knowledge (Inspiration, 2003). Neuroscientists conducted fMRI's showing there was increased activity in the brain and retention of information when graphic organizers were part of the learning process (Coates, 2008; Jonassen, Beissner, & Yacci, 1993; Stevensold & Wilson, 1990). Evidently, the collaboration between the eyes and brain is unique. Perhaps this is because the retina is a piece of the brain that grew into the eye. These two organs work together to depict three-dimensional images that gain the brain's attention and focus (Koch et al., 2006).

Transfer

Transfer, the ability to learn a skill in one area and use it in another context, is basic to the purpose of education. The lion's share of research on this topic has been in the area of gaming and the findings point to computer games being limited in scope when it comes to transfer. While gaming skills improve with play, those skills do not extend into the real world. However, one study by Jaeggi, Buschkuehl, Jonides, and Perrig (2008) defies the findings of the majority. These researchers investigated gaming in terms of short-term working memory and fluid memory, which is the ability to solve original problems where previous learning has not occurred. They found that the more an individual played a game, the greater his or her short-term working memory and fluid memory.

The research of Jaeggi et al. offers hope to educators that a skill learned on the computer will transfer into real-world activities. Continued study of technology's impact on transfer is worthy of neuroscience research and the results are worthy of continued awareness by educators.

Cooperative Learning Groups

We know through educational research that cooperative learning groups meet both the academic and social needs of students (Marzano et al., 2004). Research from neuroscience adds to these findings, informing us that positive social interactions, such as that found in group work, release oxytocin. This hormone assists in bonding and social recall, elevating our ability to connect with others and reduce stress (Heinrichs & Domes, 2008). E-learning assignments that require students to create wikis, webquests, and Google Write are brain-compatible cooperative learning tools.

Cooperative learning groups also act as a protective factor against loneliness. Individuals who are lonely suffer with more stress, higher blood pressure, and lower immune systems. Additionally, the caudate nucleas, an area of the brain associated with rewards, is not as active in lonely people. This translates into feelings of dissatisfaction and unhappiness (Cacioppo, 2009). Educators have limited influence on student friendships; but assigning group work is in the realm of classroom assignments. This strategy builds social interaction and is an antidote to feeling alone.

Learning Through Observation

Mirror neurons are a set of complex neurons that have a unique function in video games. These neurons fire with observation. In other words, mirror neurons fire in the individual observing the action, as well as neurons firing in the brain of the individual doing the action. For instance, if a person watches someone smoke a cigarette, they take a puff in their brain. This enables our brain to smile when we see a winning race or cry when someone is hurt; empathy in action (Iacoboni, 2008).

Mirror neurons mimic positive and negative characteristics and actions. Research has only begun on this subject, but scientists are finding that playing computer games that simulate caring of others influence teenagers to be more thoughtful in real life (Gentile et al., 2009). Unfortunately, compelling research also shows that adolescents, regardless of level of natural aggression, are impacted by violent video games. The more they play the game the greater the tendency to imitate the violent actions in the real world. In fact, mirror neurons make it hard for the brain to resist actions, good or bad, because they work at a subconscious level, reducing the individual's control (Iacoboni, 2008).

Mirror neurons shed an important light on learning through observation. When selecting games and other e-learning tools for the classroom it is important for teachers to consider the hidden and secondary observed curriculum, as well as the intended curriculum.

Motivation

Adolescents' passion for e-learning is palpable as they hyper-focus attempting to win, achieve, and enjoy. Researchers found that task and persistence increased for students with each correct answer, along with their levels of satisfaction. Amazingly, this time and persistence continues once they leave the schoolhouse doors, into homework time (Becta, 2004; Kinzie & Joseph, 2008). No wonder educators are eager to harness this positive energy; motivation often makes the difference between the student who struggles and the one who succeeds.

Dopamine plays a significant role in intrinsic motivation. Positive energy explodes onto the brain when dopamine is released, driving and inspiring behavior (Willis, 2011). Its affirming influence can be seen in studies done with rats. Scientists reinforced rats with dopamine every time they pressed a lever. The rats found the dopamine so addictive that they pressed the lever up to 2000 times, to the point of exhaustion, in order to receive a dopamine rush (Kalat, 2004). Similar desire and response to dopamine is seen in humans; it propels determination and accomplishment, creating feelings of euphoria and pleasure.

The trigger for a dopamine rush is receiving a reward, such as achieving an academic goal, winning a race, or kissing a mate. All create a natural high in the brain. This same pleasurable feeling is realized in computer-based instruction. When computer feedback indicates a correct prediction or answer, dopamine is released. Each jolt of dopamine triggers happiness and the craving for more in students, fueling the activity.

In this quest for dopamine a challenge is compulsory. In schools this means the content must become more rigorous as students progress—the status quo is never good enough. Once something is learned the amount of dopamine released becomes weaker and weaker with continued practice (Willis, 2011). Therefore, academics must increase in complexity to continue to be a motivating factor for students to continue the activity (Cohen et al., 2010).

Conclusion

The teenage brain experiences remarkable change as it transitions from childhood to adulthood. Quantity and quality of thinking improves due to an overproduction of dendrites and synaptic connections, pruning, and myelination. Adolescents become capable of thinking abstractly, problem solving at complex levels, and applying rational and logical thought. Additionally, the analytical frontal lobes begin to control the emotional amygdala during the teen years. This assists teenagers in emotional control and improves their ability to make good decisions. Due to the streamlining and upgrade in the teenage brain, they are particularly vulnerable to environmental stimuli.

Academically, computer-based instruction, in the form of the Internet, tutorials, and other technology, is capable of increasing achievement and engaging students. Gaming and tutorials are particularly effective in providing practice and reinforcing basic skills; graphic organizers and the Internet are conducive for encouraging higher order thinking. The case for computer-based instruction is furthered strengthened by its effectiveness as a motivator. In fact, it is difficult to find another strategy that can compete as an academic motivator for teenagers. Students are drawn to e-learning and feel a comfortable affinity for this approach to learning.

However, computer-based instruction is not without limitations and drawbacks. Research suggests gaming addictions, reflexive responses, and reduced attention spans are aggravated with computer-based instruction. These findings are worrisome and compel educators to approach e-learning with caution and balance.

Technology is shaping the world we live in, and as a result our students' brains are rewiring and restructuring. Burgeoning findings on e-learning's impact on the teenage brain help inform instruction. Tutorials, gaming, and graphic organizers are all compatible with the teenage brain. However, while computer-based instruction provides the medium, it's important for educators to recognize that the instructional design ultimately determines the level of effectiveness (Pitler et al., 2007). Crafting effective computer-based instruction is dependent upon considering in combination the research on the teenage brain and instructional technology.

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Mind, Brain, and Education: The Birth of a New Science

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ABSTRACT

In this paper, we examine the history of the emerging discipline of Mind, Brain, and Education (MBE) and explore the benefits as well as the difficulties involved in integrating neuroscience into educational policy and practice. We examine the power of neuroscience to impact practice and document the rise of neuromyths. History is on the side of the new discipline of MBE, but there is still much important work to be done to make neuroscientific findings accessible, comprehensible, and relevant to educators.

Part 1. A History of a New Field

Education in the Ancient World and Europe

Early written records show that formal education began in Egypt some time between 3000 and 500 B.C.E. Although it is impossible to establish an exact dating, the earliest accounts involve instructions from parents to children; later scribal schools were established which taught not only writing, but also wisdom (Curnow, 2010; Kugel, 2007).

The oldest center for higher learning was Nalanda University, established in the 5th or 6th century BCE, which is reported to have been visited by Buddha; although destroyed in 1193, plans are now in the works to resurrect it as Nalanda International University (Buncombe, 2010). In the Western lineage, ancient Greek aristocratic families hired "sophists" to teach rhetoric and other important skills to their children.

Philosophical academies were the first centers for adult education in the west and were specifically designed to teach for wisdom. Schools like Plato's academy (ca. 387 BC, Athens) survived hundreds of years before being closed by the Emperor Justinian I in 529AD.

The first European universities appeared in the 11th and 12th centuries. The University of Bologna was established in the Western world in 1088 and the term "university" was coined at its creation. However, public education did not begin in Europe until the 1500s. The schools were devoted to the ideals of Renaissance humanism, which revived the writings of Greece and Rome as models of the height of human knowledge. The invention of the printing press made books more available, but elementary school attendance was still limited to middle and upper class families; only children of nobles attended the humanist secondary schools.

In 1862, the United Kingdom established a school grants system through which schools received funds based on their students' performance on reading, writing, and arithmetic tests. The Education Act of 1870 later authorized the establishment of public board schools. In the United States, Thomas Paine promoted the idea of free public education in the late 1700s, but only after the efforts of people like Horace Mann, in 1852, did Massachusetts pass the first laws instating free public education. However, it took until 1918 for all U.S. states to make school attendance compulsory and, despite considerable progress over the last decade, the United Nations Millennium Development Goal of universal primary education for all children by 2015 is unlikely to be met.

The Emergence of Mind and Brain

It appears that Hippocrates (460 to 380 BCE) was the first to identify the brain as a source of human sensation, knowledge, and wisdom. Centuries later, the stoic philosophers also considered human experience to be completely embodied, although debates continued in antiquity over whether the heart or the brain was the primary organ of human psychic life.

Renaissance figures revived the classical tradition of direct investigation of nature, including the human brain. Thus, Leonardo da Vinci's sketches of a centenarian brain (1508) and Andreas Vesalius's (1543) anatomical work not only created precise visual records, but they also began to name specific areas of the brain (see Kemp, 1972, 2007). In the next century, scientific groups like the Royal Society of London, who published the first scientific journals, emerged. Among the most complete early versions of the brain were Christopher Wren's engravings for Thomas Willis' (1664) Cerebri anatome (The Anatomy of the Brain). Wren (who later designed St. Paul's Cathedral in London) was Willis' assistant and medical artist.

In 1693, John Locke wrote *Some Thoughts Concerning Education*, a manual on how to guide the child to virtue. Locke's hierarchy of values in the education of a gentleman's son centered around: virtue, wisdom, breeding, and learning. His overall curriculum emphasized starting with the fun of learning plain and simple ideas, and of building on children's existing knowledge of how subjects are interconnected (Aldrich, 1994). However, Locke (1690) set aside the question of how mind relates to brain, granting only that it might have a material substrate. But simply opening the possibility of a material substrate for the soul set the stage for Charles Bonnet. In his 1755 *Essay on Psychology* (the first book with psychology in the title), Bonnet specifically linked mind, brain and education, but without proposing any educational program.

By the 19th century there were discoveries of specific brain area functions. Broca (1862) and Wernicke (1874) established that most people have two main language areas in their left frontal (Broca) and parietal (Wernicke) lobes. Brodmann (1909) charted the primary visual motor and auditory pathways in the brain and his contemporary, Ramón y Cajal (1911) convincingly showed that the neuron was the basic functional and structural unit in the brain. All of these discoveries led people to consider the relationship between mind, learning, and the brain.

Developmental Psychology as a Precursor to MBE

William James (1899) spoke at length about the implications of psychology for how to teach young children, concluding,

> Thus are your pupils to be saved: first, by the stock of ideas with which you furnish them; second, by the amount of voluntary attention that they can exert in holding to the right ones, however, unpalatable; and, third, by the several habits of acting definitely on these latter to which they have been successfully trained. (p. 127)

Mind and brain were linked through evolutionary psychology by Hall and especially by Baldwin in the late 1800s. Most famously, through what is now called the Baldwin Effect, a proposed mechanism for specific evolutionary selection for general learning ability (Broughton, 1981). The Baldwin Effect basically suggested that when learning occurs that is beneficial to the survival of a species, then it alters the conditions of selection and eventually the genes passed on to the future descendants.[1]

Jean Piaget developed the ideas of Baldwin and others like Janet to make an enduring contribution to psychology and education. Throughout his career, Piaget strongly grounded his work in biology and tied it to education as phenotypic adaptation (Piaget, 1980). This began with Piaget's work studying children at the Maison des Petits, a progressive school associated with the Jean-Jacques Rousseau Institute, under Edouard Claparède and Pierre Bovet. From 1921-25 he was Research Director of the Jean-Jacques Rousseau Institute, Geneva, and from 1929-67 Director of the International Bureau of Education in Geneva; from 1932-71 he was also Director of the Institute of Educational Sciences at the University of Geneva. Piaget was also appointed the president of the Swiss Commission UNESCO.

Piaget's research most famously identified four stages of cognitive development (sensory-motor stage, preoperational period, concrete operational stage, and formal operational stage), but also proposed adapting these to specific educational settings, along with a biological explanation for how they were instantiated (Piaget, 1970; Smith, 2000).

Another key contributor to the MBE science discipline was Lev Vygotsky, whose ideas of cultural mediation and internalization as related to an individual's "inner speech" are still being debated today. Together with his collaborators, especially Alexander Luria, Vygotsky developed a cultural-historical psychology that also aimed to integrate studies of mind, brain, and education within a developmental framework. Vygotsky's work was important for special education in Russia at that time and he himself worked as a teacher with children with special needs early in his career. His ideas were adapted into curricula structure for school-age children by Vasili Davydov (Davydov, 1995; Yasnitsky, in press).

The approaches of Piaget and Vygotsky are combined in Kurt Fischer's Skill theory, a global theory of human development as a dynamic system that is at the forefront of current work in Mind, Brain, and Education (Fischer & Bidell, 2006; Stein & Fischer, 2011).

The Emergence of Mind, Brain, and Education

In his influential book, "The Organization of Behavior" (1949), Hebb proposed his famous Hebbian synapse rule: Neurons that fire together, wire together, explaining the mechanism of classical conditioning, and the associative learning that results when a neutral stimulus is associated with a conditioned stimulus, an associative learning concept first proposed by Aristotle that was to become a core idea in the emerging discipline of MBE.

In 1978 we saw the publication of "Brain Research and Learning" (Claycomb, 1978) by the National Education Association, and of Chall and Mirsky's "Education and the Brain." Both were well-researched efforts to integrate neuroscience and education. Tokuhama-Espinosa (2011) noted that two popular books for educators were also published around this time, Howard Gardner's "Frames of Mind" (1983) and Leslie Hart's "Human Brain, Human Learning" (1983). They were influential in that they sparked a new interest among teachers in the connection between learning and the brain.

Between 1973 and 1979 *educational neuropsychology*, another forerunner to Mind, Brain, and Education Science (MBE), came to the fore and Gazzaniga proposed incorporating functional neuroscience into teaching in his book, "*Neuropsychology: Handbook of Behavioral Neurobiology*." Michael Posner also proposed integrating the neurosciences and psychology to improve our understanding of learning.

In 1988, Gerhard Preiss, professor of Didactics at the University of Fribourg, proposed a new discipline that would combine the study of brain processes with that of pedagogy and didactics in order to optimize human learning. This is an approach that still has adherents (for example, see Sabitzer, 2011)

Recently, the emerging field of MBE science has provided an umbrella for research in neuropsychology and neurodidactics. There are two main reasons for this: MBE science studies teaching, not just learning, and the very term "educational neuropsychology" or neurodidactics implies that education and neuroscience are subfields of psychology or didactics, whereas MBE science does not (Tokuhama-Espinosa, 2011).

The Birth of MBE as a Discipline

MBE as a discipline emerged from several sources in different nations at about the same time. The Decade of the Brain (1990–1999) spurred the development of many new findings and myriad theories about the brain and learning. These were of two basic types: modular, domain-specific theories, which explained the neural mechanisms of skills such as reading, and mathematics, and abilities such as attention and memory and global theories of learning which explained how to optimize brain learning in general. At this time, Kurt Fischer and others extolled the value of neuroscience research in education and began to envision an independent field of MBE.

There was an increasing call for bidirectional collaborations between educational psychology and neuroscience and the early 1990s saw more international and interdisciplinary cooperation. In addition, several high-quality teaching interventions, based on neuroscientific research and proven in the lab, appeared. For example, new neuroscientifically based reading curricula, like RAVE-O (retrieval, automaticity, vocabulary, engagement with language, orthography) and Fast ForWord were developed and were being successfully applied in the classroom (Tokuhama-Espinosa, 2011).

In addition, by the early 1990s, early attempts by scientists to produce teacher-friendly information had accelerated, and experimental psychologist Paula Tallal and neurophysiologist Michael Merzenich organized brain-based conferences for educators through their Scientific Learning Corporation.

An important leader in this movement was the Organization for Economic Co-operation and Development (OECD), which held three international conferences—in New York (2000), Granada, Spain (2001), and Tokyo (2001)—that aimed to synthesize ideas and propose research agendas for the emerging discipline that incorporated neuroscience, psychology, and education.

In 2004, the International Mind, Brain, and Education Society (IMBES) was created and has held increasingly larger society meetings. The second IMBES conference in May 2009 showed membership is steadily on the rise.

In 1999, the first "Learning Brain EXPO" in San Diego gathered over 700 teachers and scientists, attesting to the growing popularity of anything labeled *brain-based* and the first "Learning & the Brain Conference" at Harvard University and MIT, in 1997, fostered teacher-neuroscientist encounters. The 26th conference in this series (in May 2010) drew over 2,000 people, mostly educators, showing an ever-deepening concern by learning institutions to incorporate neuroscientific research and knowledge into teacher education.

Coincidently, at the end of the 1990s there was an increase in pedagogical rethinking, including attempts to unite teachers around a set of accepted "best-practice principles" in teaching elements and curriculum/lesson planning, and in 1998, the Education Commission of the United States published a consideration of how neuroscience could have educational policy implications. Recently, books with "mind, brain, and education" label in their titles have begun to be published, for example, "The New Science of Teaching and Learning: Using the Best of Mind, Brain, and Education Science in the Classroom" (Tokuhama-Espinosa, 2010) and "The Developmental Relations Between Mind, Brain and Education: Essays in Honor of Robbie Case" (Ferrari & Vuletic, 2010). Furthermore, in an effort to develop coherence among the research findings from these diverse but connected disciplines, a new journal called "Mind, Brain, and Education" produced by the International Mind, Brain & Education Society has been developed.

Institutional Development of MBE Programs

Dartmouth College's doctorate program in psychological and brain science began in 1968, and Dartmouth's undergraduate educational degree in educational neuroscience was founded in 1990. The first dissertation on MBE science was by O'Dell (1981), called, "Neuroeducation: Brain Compatible Learning Strategies." In 1988, the Brain, Neurosciences, and Education Special Interest Group (SIG) of the American Educational Research Association (AERA) was formed out of the Psychophysiology and Education SIG, the oldest U.S. organizational entity specifically linking research in the neurosciences and education (Tokuhama-Espinosa, 2011).

But at the end of the 1990s, although teacher interest in the brain grew, few professional programs in universities offered courses in this discipline, and thus popular-press books about brain-based learning flourished to fill the void. One of the best-selling books of all time aimed at teachers, Jensen's (1998) "Teaching With the Brain in Mind" was published, in its first edition, at this time.

In 1997, Kurt Fischer and colleagues at Harvard developed a new and innovative course called "Mind, Brain, and Education" and after several years of planning (1997–2001) Harvard University launched its Master's Program in Mind, Brain, and Education in 2001–2002. Other programs available in MBE science by 2005 included those at the University of Texas at Arlington, the University of Southern California, as well as a host of international programs that also appeared around this time.

Other institutions are also beginning to explore the possibilities. The Ontario Institute for Studies in Education of the University of Toronto (OISE/UT) hosts a large Initial Teacher Education (ITE) Program and a graduate (MA and PhD) neuroscience research program. In 2007, a new elective course for teacher education candidates called "The Adolescent Brain: Implications for Instruction" was developed and the first graduate course, "Neuroscience and Education," followed in 2008. Currently, funding has been obtained to develop a website featuring new developments and research in neuroscience and education for educators and policy makers (McBride & Ferrari, in preparation).

Part 2: Implementing MBE

The Promise and the Controversy

Currently cognitive neuroscience is making rapid strides in areas highly relevant to education. New research on the development of the prefrontal cortex has led to instructional strategies that support and scaffold students' executive functions (Giedd & Lenroot, 2006; Steinberg, 2007; Van Leijenhorst et al., 2010) while research on changes in circadian rhythm occurring at puberty is relevant not only to teachers but also to parents and policy makers (Beebe, Fallone, Neha Godiwala, & Flanigan, 2008). In the same vein there is also significant new neurobiological research emerging on reading, dyslexia, mathematics instruction, dyscalculia, autism spectrum disorders, emotional and behavioral disorders, ADHD and learning and memory (Ansari, 2008; Baron-Cohen, Knickmeyer, & Belmonte, 2005; Immordino-Yang & Damasio, 2007; Narhi, Lehto-Salo, Ahonen, & Marttunen, 2010; Shaw et al., 2007; Shaywitz & Shaywitz, 2008).

It is becoming clear, that although the field of MBE is still in its infancy, knowledge of neuroscience can have a powerful effect on teaching practice. As a result educators are becoming increasingly interested in neuroscience and are motivated to incorporate new research findings into their practice (Goswami, 2006). Indeed, from the early days of psychology as a discipline, teachers have been interested in the new biologically based psychology.

However, in the past as well as in the present, there is controversy. Not everyone is convinced that neuroscience can or should support and inform education. In his "Talks to Teachers," William James (1899) famously said,

> You make a great, very great mistake, if you think that psychology, being the science of the mind's laws, is something from which you can deduce definite programmes and schemes and methods of instruction for immediate schoolroom use. Psychology is a science, and teaching is an art; and sciences never generate arts directly out of themselves. (p. 23)

More recently, John T. Bruer's influential paper, "Education and the Brain: A Bridge Too Far" (1997), challenged the educational relevance of research in neuroscience. Educators supporting Bruer (1997) have argued that teachers cannot translate neuroscience research directly into practice and propose instead that teachers should embrace cognitive psychology to better understand learning.

There is also the difficulty of convincing educators and policy makers of the value of research. Although education has a tendency to quickly adopt new ideas, decisions are usually made without the benefit of any research evidence as to their efficacy or usefulness (Hempenstall, 2006; Marshall, 1993). Maggs and White (1982) stated: "Few professionals are more steeped in mythology and less open to empirical findings than are teachers" (p. 131). Hempenstall (2006) found this to still be true, noting that Carnine (2000) found that education as a profession still ignores research that supports effective practices. In addition, Cooper, Levin, and Campbell (2009) found that despite recognizing that research should inform practice, interventions to increase the use of research evidence, particularly in high schools, is still modest at best.

Even when evidence-based programs are successful, educators may not adopt them. In an implementation study of an evidence-based program, Woodward and Gersten (1992) found that although achievement growth for the students was dramatic, and participating teachers were extremely enthusiastic about the program, one year later only two of the original seven teachers were still using the program. Carnine (2000) also found that when research results conflicted with educators' beliefs and ideology in studies such as Project Follow Through, educators and administrators ignored the findings.

Neuromyths

Although the promise of neuroscience is exciting there also needs to be caution. Goswami (2006) found that, as a result of educators' interest in neuroscience, teachers and school boards are being bombarded with books, courses, and educational packages that encourage them to create "brain-based classrooms" and to use "brain-based curriculum and instruction." Unfortunately, many of these programs are based on oversimplifications of research findings in neuroscience while others are based on myths about the brain. For example, the myth of left- and right-brained learners—an overgeneralization of hemispheric specialization, the myth of the brain-based classroom—an overgeneralization of research on the effect of stress on brain functioning and the myth that there are layers of the brain that match layers of the curriculum. There are also many commercial products being developed which are based not only on myths, but also on misinterpretations of research findings such as the concept of brain neuroplasticity. Teachers and schools are often told that they need to invest in expensive software programs that can rewire the brain, "cure" learning problems and improve academic performance (Blakemore & Frith, 2005; Geake, 2008).

These myths have developed, in part, because research findings from so many disciplines (among them neuroscience, genetics, physiology, and cognitive psychology) have implications for educational practice. The challenge then is how to translate this complex research into educational practice without losing the integrity of that research, while also making it accessible, comprehensible, and relevant to educators (Purdy & Morrison, 2009).

Bridging the Gap: Teaching for Wisdom vs. Information

Gregorian (2007) states that one of modern society's greatest challenges is how to distinguish between information and real knowledge, and further how to transform such knowledge into wisdom. He goes on to say that, given the current overload of information and knowledge, it is the responsibility of educators to teach students how to recognize and use knowledge that is relevant, reliable, and useful.

This is not an easy task, particularly in the field of neuroscience, where much of the research information is technical in nature and difficult to understand and translate into lay terms that can be understood by educators, parents, and policy makers who may have little or no background in the sciences. However, there is now an emerging field called knowledge mobilization (KM), designed to address the research-practice gap. Knowledge mobilization is now recognized as being a key ingredient of all research across disciplines and countries (Cooper et al., 2009).

In addition, "evidence-based decision making" (EBDM) and evidence-informed policy and practice have become top priorities internationally (Davies, Nutley, & Smith, 2000; Nutley, Walter, & Davies, 2007).

In 2002, the U.S. Department of Education established the Institute of Education Sciences (IES) to support a more evidence-based approach to education and in Canada, the Canadian Council on Learning (CCL) was developed to support and promote evidence-based decisions about learning. In September 2005, CCL launched "The 21st Century Learning Initiative." One of its goals is to "facilitate the development of new approaches to learning that draw upon the most current insights into the human brain" (Canadian Council of Learning).

In order to bridge the research-practice gap, Goswami (2006) suggests that neuroscientists and researchers must speak directly to teachers. There are now a growing number of reliable organizations that actively support this kind of endeavor using technology and the Internet. For example, The Society for Neuroscience (www.sfn.org/) and the Dana Foundation (www.dana.org/resources/brainweb/) among others, have excellent vetted websites. In addition, many universities have also developed informative and reliable websites containing neuroscientific information that is not only relevant, reliable, and useful but that has also been transformed into a format easily understood by educators. As previously mentioned, the authors have just received funding to develop such a website at the University of Toronto.

The Power of Neuroscience

Research shows that neuroimages such as MRIs are persuasive to both educators and to the public (Weisberg, Keil, Goodstein, Rawson, & Gray, 2008). Feigenson (2006) hypothesized that neuroimages reduce psychosocial complexities to features of the brain that can be directly viewed. When faced with complex, unfamiliar information, individuals tend to use a reductionist structure to reduce psychological phenomena to their lower level neuroscientific counterparts (Weisberg et al., 2008). In addition, neuroscience is associated with powerful visual imagery, which tends to render scientific claims more convincing. This has far-reaching implications for both teacher education and professional development.

It appears that the introduction of neuroscience into an Initial Teacher Education Program can support and facilitate the transfer of neuroscientific knowledge into best practices in the classroom. It was found that over 90% of 95 new teachers who had taken a course on the adolescent brain stated that their knowledge of neuroscience research had significantly impacted their classroom practice (McBride & Todd, 2008; McBride & Pomeroy, 2009). Research on learning has shown that it is only when the learner understands the underlying principles that knowledge can be applied successfully (Bransford, Brown, & Cocking, 1999). As early as 1693, John Locke in "Some Thoughts Concerning Education" proposed that individuals gain knowledge best when they gradually combine simple ideas into more complex ones.

Students in a Bachelor of Education (B. Ed.) teacher education program reported that their knowledge of the neural basis of brain functioning allowed them to apply underlying processes to their teaching. One could hypothesize that their knowledge of the adolescent brain provided a cohesive conceptual framework within which they could frame the purpose and use of specific instructional strategies. For example, an understanding of the synaptic exuberance and pruning that occurs during adolescence in the prefrontal cortex gave students a rationale for the use of scaffolding. One said, "For the first time I really understood why scaffolding was necessary and I used it a lot during practicum" (Anonymous survey, 2008). Another student said, "I was much more patient because I understood what was happening to my students as a result of the physical and neurobiological changes they were undergoing" (Anonymous survey, 2009).

However, although the teachers reported that a knowledge of neuroscience had significantly impacted their practice they found it difficult to articulate how this had happened. Cooper and Levin (2010) state that research use can occur in many different ways and over a long period of time and can be very difficult to track and measure. More research is needed to identify how and why neuroscientific knowledge impacts practice and policy.

Conclusion

The time has come for Mind, Brain, and Education to be fully recognized as a science, with the potential to have a powerful impact on educational policy and practice. Educators and school boards are increasingly coming under media scrutiny and increased pressure to improve educational outcomes at a time when educators, policy makers, and the public have become fascinated with "brain research." At the same time, governments and policy makers are promoting and supporting Evidence-Based Decision Making and Knowledge Transformation. These are ideal conditions for the growth of Mind, Brain and Education. However, while there has been significant progress in developing Mind, Brain, and Education as a science, there is still much important work to be done to make neuroscientific findings accessible, comprehensible, and relevant to educators, policy makers, and parents. While teachers are eager to use the latest neuroscientific evidence to inform their practice, we must be careful to guard against "neuromyths" and "fads" by continuing to meet the challenge of retaining the integrity of the research while transforming the findings into useful, relevant, and comprehensible knowledge. We also need to continue to have neuroscience researchers and educators collaborate to develop Mind, Brain, and Education programs and courses that can transform new neuroscientific research into a format that can be applied in educational settings. Mind, Brain, and Education is a science that shows great promise. It can, and should, continue to be fruitfully pursued in the future as ever more evidence emerges about the brain that is of great relevance to education.

Notes

1. This theory had profound influence on the belief that both biology and experience mutually impact learning outcomes. For example, in her eloquent book, *Proust and the Squid*, Maryanne Wolf (2007) illustrates how reading has changed the human brain through dramatic evolutionary processes, a concept that is reinforced by Stanislaus Dehaene's (2009) belief in neuronal recycling, or the reuse of evolutionarily older areas of the brain for new needs, such as reading, which has only been required for about the past 5000 years.

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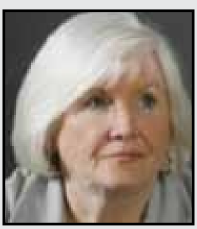

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Executive Function in the Classroom: Neurological Implications for Classroom Intervention

Harriet Greenstone, Centre MDC

ABSTRACT
Executive function skills are critical for both school and personal success, but have been traditionally under-addressed in academic settings. Recent advances in the field of neuroscience, and specifically those dealing with neuroplasticity, have provided new understanding of the causes of executive dysfunction and how we can use this information to remediate these weaknesses in the classroom, even for those with typical executive function development, by teaching these skills as part of the curriculum.

Introduction

Despite increased efforts in recent years toward zero tolerance for aggression, oppositional behaviour, and bullying, these behaviours persist in our classrooms. And despite our many pedagogical and curricular advances, too many students are still not completing high school, or are graduating without the skill sets necessary to succeed in post-secondary studies.

This article proposes that although educators may be aware of executive function skills, they may be overlooking their important implication in the foundation (and thus the remediation) of both academic and behavioural problems. Executive function skills are a collection of skills that are critical for goal-directed behaviours, social behaviours, and emotional well-being. It's hard to imagine being successful in the classroom, or indeed in life, without them. They are at least as important as reading and mathematics skills, arguably even more important, yet while progress has been made in the research domain for executive functioning, much less is being seen in practice.

There is no definitive list of what constitutes executive function skills. Researchers generally agree on the content, but there is often overlap and differential labelling of the various skills. A good working model can be found in the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000), which measures the executive function domains shown in the table below.

Table 1
Executive Function Domains (BRIEF)

DOMAIN	DESCRIPTION
Inhibit	Ability to resist impulses and inhibit one's behaviour when appropriate.
Shift	Ability to switch attention, deal with transitions and tolerate change, think flexibly, shift focus.
Emotional control	Ability to control or modify one's emotional responses.
Initiate	Ability to start an activity or task, to come up with one's own ideas and problem-solving approaches.
Working Memory	Ability to retain information in one's memory and actively use or manipulate it to complete a task (e.g., to follow complex instructions, or do multi-step activities such as mental arithmetic).
Plan/Organize	Ability to set goals, anticipate future developments, predetermine steps necessary to complete a goal, organize information, identify key concepts or ideas, employ complex (or even simple) motor planning.
Organization of materials	Ability to keep track of one's materials and belongings and maintain them in an organized state, available for use when needed.
Monitor	Ability to assess one's progress on a task (monitoring accuracy, time management, effectiveness of strategies, etc.) and ultimate performance on the task, and the ability to monitor one's behaviours and the effect they have on others.

Executive Dysfunction: A Neurological Problem, Not a Character Flaw

The frontal lobe, often referred to as the brain's "control centre," is considered the seat of executive functioning. This is where the anterior cingulate is located, which is often referred to as the "oops centre" because of its role in helping us anticipate risks and keeping us from acting in a way that is detrimental or inappropriate. This structure in the brain has been associated with many executive function skills, including emotional self-control, problem solving, divided attention, recognizing errors or conflicting information, and adaptive behaviour in changing circumstances (Allman, Hakeem, Erwin, Nimchinsky, & Hof, 2001; Powell & Voeller, 2004). Although the anterior cingulate is not the only part of the brain involved in executive function skills, its role is essential, and demonstrates that the roots of executive dysfunction lie in the brain, not in character flaws.

It's not surprising that a glitch in the neural circuitry of the frontal lobe can lead to problems in many areas of executive functioning—just as there are neurological, neuropsychological, and/or neurochemical underpinnings to many other disorders, including learning disabilities, ADHD, Obsessive Compulsive Disorder, Autism Spectrum Disorders, etcetera (all disorders with which executive function weaknesses are commonly associated).

What is surprising, however, is the disparate response to executive dysfunction in the classroom, relative to the specialized instruction techniques and other interventions that have been devised to help students with these other disorders. We certainly don't punish a child with dyslexia. But as Harvard psychologist Dr. Ross Greene (2009) points out in his book *Lost at School*, children with weak organizational, behavioural, or emotional skills are often met with discipline or consequences, even though they may not know what they have done wrong or how to do it right.

Hopefully, just as we no longer blame "refrigerator mothers" for autism, or demand that learning-disabled students "try harder!," our growing understanding of the neurological basis for executive dysfunction will lead to effective classroom interventions to help these students (and indeed even neurologically typical students) reach their academic and personal potential.

How to Know if a Student Has Weak Executive Function Skills

Unfortunately, most students don't show up on the first day of school, clutching a pencil in one hand and a full psycho-educational report in the other. And even if they do, and you're lucky enough to find they have been tested for executive functioning, there's a caveat. Many measures test for a well-circumscribed and small subset of executive function skills, so the results cannot be generalized across the whole span of skills. You must also keep in mind that such testing can include detailed instructions (often repeated), ongoing feedback, and significant external structure. Also, such tests are typically administered in a private office, in a relatively stress-free environment, with only one supportive adult present. This is the best possible scenario for many children and adolescents with executive function difficulties, and one where they're very likely to do their best. These tests don't pretend to measure the whole range of the individual's executive skills, captured in a normal daily environment. And even when results do identify specific executive function weaknesses, they are often misunderstood, considered too small and specific to be of consequence, or beyond the scope of classroom intervention.

Broader, more "real life" measures can be obtained through behaviour ratings questionnaires completed by parents or caregivers, teachers, and even the students themselves if they are old enough. But by definition, these ratings are subjective.

All these findings can be helpful, but they should be augmented by a teacher's own observations in the classroom—and in many cases, that will be all there is to go on. Table 2 shows how weaknesses in some aspects of executive function might appear in school-aged children. Several of these skills are behavioural in nature, and others are metacognitive. An individual may be weak in some skills and competent or even strong in others. The weaknesses may be "stand-alone" or part of a mix of other difficulties. But whatever the presentation, the classroom challenges are the same.

Table 2
Classroom Manifestations

PROBLEMS WITH …	MIGHT LOOK LIKE THIS …
Inhibit	• Impulsivity — will often start on an activity before listening to instructions • Difficulty staying in line when moving around the school, or even staying in the classroom • Interrupting others or calling out in class • Needing more adult supervision and structure

PROBLEMS WITH …	MIGHT LOOK LIKE THIS …
Shift	• Difficulty changing tasks, places, approaches to problems • Difficulty tolerating change (like a substitute teacher, or a change in a planned activity) • Black and white thinking, can't see the grays, can't let go (not *won't* let go … an important distinction)
Emotional control	• Outbursts, sudden/frequent mood changes, emotionally reactive, periods of excessive emotional upset
Initiate	• Needs to be told to start a task, even if they're willing to do it • Ready to start a task, but doesn't know where to begin (i.e., doesn't know the first step, needs to have the steps broken down) • Has trouble coming up with ideas (for a project, or even what to do in play time) • Rarely takes initiative in chores or homework (doesn't know how)
Working memory	• Trouble remembering things (phone numbers, instructions) • Losing track of what they're doing • Forgetting the purpose of an errand • Frequently failing to stick to an activity (poor sustained attention)
Plan/organize	• Underestimating time to complete a task, or level of difficulty • Waiting to the last minute to begin a big project • Mixes up the steps involved in a project, or in any multi-step sequence • Failing to understand main points in written or verbal material • Losing track of homework assignments • Getting caught up in details and losing track of the "big picture"

PROBLEMS WITH …	MIGHT LOOK LIKE THIS …
Organization of materials	• Trouble keeping school materials/belongings organized • Leaving thing at home that should be at school, and vice versa • Locker/desk/schoolbag is a mess • Frequently losing things • Failure to have materials ready for projects/assignments
Monitor	• Difficulty assessing their own performance after finishing a task, assessing what works and what doesn't work • Difficulty recognizing and keeping track of the effect their behaviours have on others

Deficits in executive function have additional implications, beyond the classroom manifestations described in Table 2. For example, Elizabeth Kelley, Assistant Professor of Developmental Psychology at Kingston's Queens University, found that the emotional control measure of the BRIEF was identified as a significant predictor of being bullied, because a child with weak emotional control is so reactive (as cited in MacReady, 2011). A student with poor inhibitory and emotional control, who doesn't grasp the effect of his or her behaviours on others, will likely have impaired social skills. A student with weaknesses in working memory, organization, and the ability to plan and initiate tasks is likely to have deficits in such academic enablers as study skills, motivation, and/or engagement—which have been linked to academic success (DiPerna & Elliott, 2002).

Neuroplasticity and Remediation of Executive Dysfunction

Children with deficits in attention, memory, learning, etcetera have traditionally been treated with school accommodations, medication when appropriate, and strategies and therapies designed to modify these weaknesses or at least teach the child to understand and manage them. These are all effective, and will continue to be a vital part of any intervention plan.

But now, thanks to recent advances in the field of neuroscience, we can add to our repertoire of helpful interventions, even for such traditionally challenging areas as emotional regulation and lack of inhibitory control. Researchers like Canadian psychiatrist Norman Doidge have promulgated the notion of neuroplasticity, and provided new understanding of how the brain works. We now know that the right exercises and activities can build new circuitry in the brain, and strengthen areas of identified weaknesses. Essentially, the brain can learn to bypass neural pathways that aren't working and build new ones—not just in childhood, but through adolescence and even adulthood (Doidge, 2007).

In fact, fMRI studies indicate that some neurological functions, such as emotion processing and cognitive appraisal systems, only develop around the time of puberty. British researchers Blakemore and Choudhury (2006) speculated that these findings point to "a period of synaptic reorganisation" when adolescent brains might be particularly responsive to efforts to regulate executive function and social cognition.

Such efforts were the subject of a study by researchers Meltzer, Pollica, and Barzillai (2007), who examined methods of teaching executive function processes such as study skills in the classroom. In addition to providing many specific strategies, they proposed the following Principles of Effective Strategy Instruction:

- **"Strategies for teaching executive function processes should be directly linked with the curriculum"**—which appears to be more effective than when these skills are taught in isolation and are unrelated to the students' classroom work. Even if a student is participating in an extra-curricular study skills program, this could still be accomplished by the teacher and tutor collaborating, to ensure the material being used is based on current classroom subjects.

- **"Metacognitive strategies should be taught explicitly"**—using very literal and concrete terms, and including frequent modeling and repetition. It is important to also teach the students exactly how each strategy will help them (e.g., "This strategy will help you identify the key points in any text").

- **"Strategies should be taught in a structured, systematic way"**—again, incorporating frequent modeling, feedback, and opportunities for repeated practice, in order for these skills to be internalized and generalized. It is important to recognize that individual strategies are not "one size fits all."

What works for one student might not work for another. Students should be encouraged to recognize what works best for them, so strategies can be adapted accordingly.

- **"Strategy instruction should address students' motivation and effort"**—It is critically important for students to (a) understand their own strengths and weaknesses, and (b) see that these strategies will lead to improved grades. Without either component, they are unlikely to use them. Step (a) can be challenging, when dealing with a student who has experienced years of failure and frustration and might be emotionally fragile. It is best accomplished in private discussions, with equal emphasis on both strengths and weaknesses, delivered in a clearly supportive, non-judgmental manner. A good approach to Step (b) would be to break down tasks or assignments into small, accomplishable units, so the students can experience successes and build on them.

Meltzer et al. also stressed the importance of developing a "culture of strategy use" in the classroom, by using methods such as encouraging students to keep individual notebooks of strategies that have worked best for them, and teachers grading students not just on the final results of tests or assignments, but also on the strategies they used to achieve them.

This approach to strategic learning is a natural fit with the work of Stanford University's Carol Dweck (2008). She believes that students who understand that brain power is dynamic (i.e., that it can be exercised and strengthened) fare better academically than those who believe their intellectual abilities were determined at birth and cannot be altered. The approaches she advocates, such as teaching students how brain exercises can stimulate neural growth (and improved grades), also strengthen important executive function skills like cognitive flexibility and self-monitoring.

Some specific strategies that may be taught to and employed by all students, not just those with executive dysfunction, would include time and work organizers, colour-coded and/or sectioned notebooks, calendars to keep track of deadlines and monitor progress, task analysis checklists, memory aids such as mnemonics, an understanding of whether they are strong auditory or visual learners and techniques adapted to those styles (audio recording of classes, detailed written instructions of assignments, etcetera), and opportunities to develop important work habits, such as breaking down problems or projects into manageable "chunks," realistically estimating time demands, generating alternative solutions and selecting the best one, and taking time to pause, reflect, and consider options before impulsively acting upon a first thought. These types of strategies have important implications even beyond the academic years. They encourage self-reliance and self-knowledge skills which would benefit any student, and should be applied in all classes, so they may begin to be generalized. Explaining to parents what appears to work best for their child may encourage them to reinforce these approaches at home when helping with homework or in other activities, again increasing the likelihood that the strategies will be internalized and generalized across environments.

Dealing with students with executive function weaknesses manifested in emotional, behavioural, and social challenges can be equally amenable to remediation, again based on an understanding of the deficits that give rise to these behaviours.

For example, Greene (1998) has done a great deal of clinical work with "explosive children." He explains that their "meltdowns" are manifestations of inflexibility, rather than opposition or bad behaviour. He offered at the time of this book a whole new way of thinking—that punishing such behaviour, or even rewarding the cessation of these outbursts, would do nothing to remediate the underlying problem. He believes that if these children *could* behave, they would behave; the problem is that they lack the skills to respond adaptively to the demands being placed on them.

Greene developed a process called Collaborative Problem Solving ("CPS"). He observed that children with emotional or behavioural challenges are almost always lacking a number of underlying executive function skills—such as the ability to deal with change, manage emotions, understand how their behaviours impact others, etcetera. He refers to these as "lagging skills." His CPS model is based on identifying the "unsolved problems," or antecedents that trigger the child's challenging behaviours (such as having a substitute teacher, or not knowing where to sit in the cafeteria), and then working collaboratively with the child to resolve the problems, one by one, by identifying and remediating the underlying lagging skills. He acknowledges it is a slow, repetitive process, but it is only by repetition that the child begins to learn to recognize his or her strengths and weaknesses, build confidence and motivation, and develop more appropriate adaptive responses to challenging situations.

The approaches of both Meltzer et al. and Greene to remediating weaknesses in executive function stress the importance of developing self-awareness, increasing motivation, and using repetition to encourage internalization and generalization (or in neurological terms, forging and strengthening new neural pathways).

For illustration purposes, the following are hypothetical cases describing how these techniques could be applied in the classroom.

Case 1 (Eric)—Executive Control Skills: Initiation, Organization, and Planning[1]

Scenario:

Eleven-year-old Eric has to write a two-page essay on a country of his choosing. While the majority of his fellow fifth-graders dive into the task with confidence, Eric has no idea where to begin. He hasn't a clue where to find any of his research, let alone which country to choose. He conveniently leaves his agenda at school and although he pretends to be working in his room every evening, Eric actually spends the time playing computer games. A month later, Eric's parents are shocked to receive a call from his teacher, who informs them that Eric got a zero on his project—an assignment they never even knew he had.

Challenges:

Although Eric's teacher had provided the class with an outline of her expectations for the project and research tips, Eric was either in a daze during class or too ashamed to admit he hadn't understood the instructions. On his own, Eric is not able to break down a task. He has poor planning, time management, and organizational skills and does not know how to initiate a task. He feels stupid and grows increasingly anxious as the deadline approaches. So he does the only thing he can think of to make the problem go away—he ignores it.

Remediation Strategies:

Eric's parents and teachers need to collaborate to ensure he receives the additional support he requires both at school and at home around assignments. For example, until Eric has gained the confidence and skills to take responsibility for his work, the teachers could verify that assignments are properly recorded in Eric's agenda, which his parents would then check each night. Eric's teachers could also spend a few minutes with Eric privately (before or after school) to make sure he understands what is expected of him, and provide written instructions for both Eric and his parents to consult.

At home, a helpful strategy would be to teach Eric to break the project down into small, manageable parts. In mutually devising a time line with his parents, or a colour-coded "Assignment Calendar" (Spizman & Garber, 1994) in which each step is identified and given a deadline, working backwards from the project's due date, Eric would have a visual reminder of his responsibilities that he could refer to again and again, and a way to concretize his progress.

Eric would also benefit from study skills instruction, ideally built into the classroom curriculum (benefitting his peers as well), where he would learn techniques such as time management skills, brainstorming techniques, how to select a topic for an assignment, how to transfer thoughts onto paper, and how to compose a list of questions to be answered.

Above all, Eric needs support, encouragement, and reinforcement. Despite the fact that his behaviour may be frustrating to his parents and teachers, they need to remember that Eric is not intentionally acting lazy or difficult; he too is frustrated and anxious, at least partially as a result of his executive dysfunction, and his dishonesty was his way of compensating for feelings of inadequacy and embarrassment.

Case 2 (Gaby)—Executive Control Skills: Emotional Control, Inhibit, Monitor

Scenario:

Fourteen-year-old Gaby has been diagnosed with ADHD-Mixed Type. Medication helps her focus attention, but she's still struggling with impulsivity and frequently annoys classmates with her constant questions and interruptions. After years of negative comments, rolling eyeballs, and being told she's too lazy to think for herself and just attention-seeking, Gaby has developed a hair-trigger temper and she's recently become involved in schoolyard fights with other girls.

Challenges:

Gaby's teacher has a good understanding of Gaby's problems, including difficulties predicting the probable outcomes of her actions, thinking of options to behaviours, negative thoughts that nobody likes her and she's "always getting blamed for nothing," and she understands how Gaby's behaviours disrupt and annoy others. But as much as she'd like to help Gaby, she doesn't know where or how to start to help her.

Remediation Strategies:

Gaby and her teacher would benefit from Greene's Collaborative Problem-Solving approach. The teacher has already made a good start, with her list of "lagging skills." She could speak to Gaby and her parents to see if she could come to school earlier, or stay a little later, so they'd have time to talk privately and try to work on these problems together. The first goal of these meetings would be to gain Gaby's trust, by encouraging her to talk about her feelings and problems, and demonstrating that the teacher's motivation to help her is sincere and empathetic. Together, they would develop a list of "unsolved problems" that Gaby agrees she'd like to resolve, and then pick one to start working on.

For example, they might choose her frequent verbal interruptions during class. Talking about it in more detail, Gaby might reveal that she panics, afraid that if she doesn't ask a question as soon as it pops into her mind, she won't be able to understand the rest of the lesson. Or she might feel she has to get a comment "out of her head" before she can focus. Whatever the reason, just talking about it will help Gaby to become more self-aware. She should also be encouraged to think about the possible consequences of this behaviour (annoys classmates, perceived as attention-seeking, etcetera)—something she has probably never considered. It might require some guidance and leading questions, but thinking about it from a cause-and-effect perspective exercises another executive function skill. This sets the stage for the next step—generating concrete alternatives and working collaboratively on problem-solving strategies. They might try counting every interruption for one day, and then make a game out of seeing if Gaby can reduce the number by one, every day for a week. This would exercise even more executive function skills—monitoring her own behaviour, and practicing inhibition.

If a strategy doesn't work, it shouldn't be considered a failure, but an opportunity to think of another one, keeping in mind that even the process of devising possible solutions is having beneficial effects. And every success will increase Gaby's motivation to work on the next problem.

Conclusion

Advances in classroom curricula often come hand in hand with increased demands on students to have higher order thinking skills at increasingly younger ages. When they can't meet these demands, whether due to executive dysfunction or simply a lack of experience developing executive function skills, then frustration, failure, dropping out (literally or figuratively), and maladaptive behaviours like meltdowns and shutdowns are the natural sequelae. Pedagogical strategies should therefore address not just *what* to learn in the classroom, but *how* to learn in the classroom—cognitively, emotionally, and behaviourally. The latter requires good executive functioning, and the good news is that with recent and ongoing advances in our understanding of how the brain continues to adapt to new learning, even through adolescence and adulthood, we can now devise classroom strategies to hone these very important skills, in all students.

Notes

1. This scenario is excerpted and adapted from the author's quarterly column in *Exceptional Family Magazine*, in an article entitled "Fine-tuning Executive Function & Emotional Regulation," first published Summer 2008.

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We Feel, Therefore We Learn: The Relevance of Affective and Social Neuroscience to Education

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Note: The lead author appears twice in this issue of LEARNing Landscapes: first in the reprint cited below, and next, in an accompanying follow-up article that features poetry from her daughter Nora Ming-Min Yang.

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ABSTRACT

Recent advances in neuroscience are highlighting connections between emotion, social functioning, and decision making that have the potential to revolutionize our understanding of the role of affect in education. In particular, the neurobiological evidence suggests that the aspects of cognition that we recruit most heavily in schools, namely learning, attention, memory, decision making, and social functioning, are both profoundly affected by and subsumed within the processes of emotion; we call these aspects *emotional thought*. Moreover, the evidence from brain-damaged patients suggests the hypothesis that emotion-related processes are required for skills and knowledge to be transferred from the structured school environment to real-world decision making because they provide an *emotional rudder* to guide judgment and action. Taken together, the evidence we present sketches an account of the neurobiological underpinnings of morality, creativity, and culture, all topics of critical importance to education. Our hope is that a better understanding of the neurobiological relationships between these constructs will provide a new basis for innovation in the design of learning environments.

Recent advances in the neuroscience of emotions are highlighting connections between cognitive and emotional functions that have the potential to revolutionize our understanding of learning in the context of schools. In particular, connections between decision making, social functioning, and moral reasoning hold new promise for breakthroughs in understanding the role of emotion in decision making, the relationship between learning and emotion, how culture shapes learning, and ultimately the development of morality and human ethics. These are all topics of eminent importance to educators as they work to prepare skilled, informed, and ethical students who can navigate the world's social, moral, and cognitive challenges as citizens. In this article, we sketch a biological and evolutionary account of the relationship between emotion and rational thought, with the purpose of highlighting new connections between emotional, cognitive, and social functioning, and presenting a framework that we hope will inspire further work on the critical role of emotion in education.

Modern biology reveals humans to be fundamentally emotional and social creatures. And yet those of us in the field of education often fail to consider that the high-level cognitive skills taught in schools, including reasoning, decision making, and processes related to language, reading, and mathematics, do not function as rational, disembodied systems, somehow influenced by but detached from emotion and the body. Instead, these crowning evolutionary achievements are grounded in a long history of emotional functions, themselves deeply grounded in humble homeostatic beginnings. Any competent teacher recognizes that emotions and feelings affect students' performance and learning, as does the state of the body, such as how well students have slept and eaten or whether they are feeling sick or well. We contend, however, that the relationship between learning, emotion and body state runs much deeper than many educators realize and is interwoven with the notion of learning itself. It is not that emotions rule our cognition, nor that rational thought does not exist. It is, rather, that the original purpose for which our brains evolved was to manage our physiology, to optimize our survival, and to allow us to flourish. When one considers that this purpose inherently involves monitoring and altering the state of the body and mind in increasingly complex ways, one can appreciate that emotions, which play out in the body and mind, are profoundly intertwined with thought. And after all, this should not be surprising. Complex brains could not have evolved separately from the organisms they were meant to regulate.

But there is another layer to the problem of surviving and flourishing, which probably evolved as a specialized aspect of the relationship between emotion and learning. As brains and the minds they support became more complex, the problem became not only dealing with one's own self but managing social interactions and relationships. The evolution of human societies has produced an amazingly complex social and cultural context, and flourishing within this context means that only our most trivial, routine decisions and actions, and perhaps not even these, occur outside of our socially and culturally constructed reality. Why does a high school student solve a mathematics problem, for example? The reasons range from the intrinsic reward of having found the solution, to getting a good grade, to avoiding punishment, to helping tutor a friend, to getting into a good college, to pleasing his/her parents or the teacher. All of these reasons have a powerful emotional component and relate both to pleasurable sensations and to survival within our culture. Although the notion of surviving and flourishing is interpreted in a cultural and social framework at this late stage in evolution, our brains still bear evidence of their original purpose: to manage our bodies and minds in the service of living, and living happily, in the world with other people.

This realization has several important implications for research at the nexus of education and neuroscience. It points to new directions for understanding the interface of biology, learning, and culture, a critical topic in education that has proven difficult to investigate systematically (Davis, 2003; Rueda, 2006; Rueda, August, & Goldenberg, 2006). It promises to shed light on the elusive link between body and mind, for it describes how the health and sickness of the brain and body can influence each other. And importantly, it underscores our fundamentally social nature, making clear that the very neurobiological systems that support our social interactions and relationships are recruited for the often covert and private decision making that underlies much of our thought. In brief, learning, in the complex sense in which it happens in schools or the real world, is not a rational or disembodied process; neither is it a lonely one.

Reasoning, Decision Making, and Emotion: Evidence From Patients With Brain Damage

To understand why this is so, we begin with some history, and a problem. Well into the 1980s, the study of brain systems underlying behavior and cognition was heavily dominated by a top-down approach in which the processes of learning, language, and reasoning were understood as high-order systems that imposed themselves upon an obedient body. It is not that emotions were completely ignored or that they were not viewed by some as having a brain basis. Rather, their critical role in governing behavior, and in particular rational thought, was overlooked (Damasio, 1994). Emotions were like a toddler in a china shop, interfering with the orderly rows of stemware on the shelves.

And then an interesting problem emerged. In a research atmosphere in which cognition ruled supreme, it became apparent that the irrational behavior of neurological patients who had sustained lesions to a particular sector of the frontal lobe could not be adequately accounted for by invoking cognitive mechanisms alone. After sustaining damage to the ventromedial prefrontal cortex, these patients' social behavior was compromised, making them oblivious to the consequences of their actions, insensitive to others' emotions, and unable to learn from their mistakes. In some instances, these patients violated social convention and even ethical rules, failing to show embarrassment when it was due and failing to provide appropriate sympathetic support to those who expected it and had received it in the past.

These patients' ability to make advantageous decisions became compromised in ways that it had not been before. In fact, there was a complete separation between the period that anteceded the onset of the lesion, when these patients had been upstanding, reliable, and foresightful citizens, and the period thereafter, when they would make decisions that were often disadvantageous to themselves and their families. They would not perform adequately in their jobs, in spite of having the required skills; they would make poor business deals in spite of knowing the risks involved; they would lose their savings and choose the wrong partners in all sorts of relationships. Why would patients suffering from compromised social conduct also make poor decisions about apparently rational matters, such as business investments?

The traditional way to explain these patients' symptoms had been that something had gone wrong with their logical abilities or their knowledge base, such that they could no longer make decisions in a rational way. But, in fact, with further testing, it became apparent that these patients did not have a primary problem with knowledge, knowledge access, or logical reasoning, as had previously been assumed. To the contrary, they could explain cogently the conventional social and logical rules that ought to guide one's behavior and future planning. They had no loss of knowledge or lowering of IQ in the traditional sense. Instead, it gradually became clear that disturbances in the realm of emotion, which had been viewed as a secondary consequence of their brain damage, could provide a better account of their poor decision making. Those emotional aspects included a diminished resonance of emotional reactions generally as well as a specific compromise of social emotions, such as compassion, embarrassment, and guilt. By compromising the possibility of evoking emotions associated with certain past situations, decision options, and outcomes, the patients became unable to select the most appropriate response based on their past experience. Their logic and knowledge could be intact, but they failed to use past emotional knowledge to guide the reasoning process. Furthermore, they could no longer learn from the emotional repercussions of their decisions or respond emotionally to the reactions of their social partners. Their reasoning was flawed because the emotions and social considerations that underlie good reasoning were compromised (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; Damasio, Tranel, & Damasio, 1990, 1991).

In retrospect, these patients provided a first glimpse into the fundamental role of emotion in reasoning and decision making. Missing a brain region that is now understood as needed to trigger a cascade of neurological and somatic events that together comprise a social emotion, such as embarrassment, compassion, envy, or admiration, their social behavior suffered. This is significant in itself, but even more intriguing was the realization that, without the ability to adequately access the guiding intuitions that accrue through emotional learning and social feedback, decision making and rational thought became compromised, as did learning from their mistakes and successes. While these patients can reason logically and ethically about standard cognitive and social problems in a laboratory setting (Saver & Damasio, 1991), out in the real world and in real time, they cannot use emotional information to decide between alternative courses of action. They can no longer adequately consider previous rewards and punishments or successes and failures, nor do they notice others' praise or disapproval. These patients have lost their ability to analyze events for their emotional consequences and to tag memories of these events accordingly. Their emotions are dissociated from their rational thought, resulting in compromised reason, decision making, and learning.

What does this mean for our argument about relevance to education? In addition to these patients, further evidence from psychophysiological and other studies of brain-damaged and normal people has allowed us to propose specific neural mechanisms underlying the role and operation of emotional signaling in normal and abnormal decision making (Bechara, 2005; Bechara & Damasio, 1997; Damasio, 1996). While the details of these neural mechanisms and evidence are beyond the scope of this article, taken as a whole, they show that emotions are not just messy toddlers in a china shop, running around breaking and obscuring delicate cognitive glassware. Instead, they are more like the shelves underlying the glassware; without them cognition has less support.

To recap, the prefrontal patients we have described have social deficits. We have argued that these are fundamentally problems of emotion and therefore manifest as well in the realm of decision making. The relationship between these symptoms is very informative, in that it suggests that hidden emotional processes underlie our apparently rational real-world decision making and learning. Furthermore, this relationship underscores the importance of the ability to perceive and incorporate social feedback in learning.

While the relevance of these insights to educational contexts has not yet been empirically tested, they lead us to formulate two important hypotheses. First, because these findings underscore the critical role of emotion in bringing previously acquired knowledge to inform real-world decision making in social contexts, they suggest the intriguing possibility that emotional processes are required for the skills and knowledge acquired in school to transfer to novel situations and to real life. That is, emotion may play a vital role in helping children decide when and how to apply what they have learned in school to the rest of their lives. Second, the close ties between these patients' decision making, emotion, and social functioning may provide a new take on the relationship between biology and culture. Specifically, it may be via an emotional route that the social influences of culture come to shape learning, thought, and behavior.

While more work on the educational and cultural implications of these findings is warranted, interestingly, and sadly, some further insights into the biological connections between learning, emotion, and social functioning, especially as they relate to our hypothesis about culture, can be gleaned from another group of patients that has been discovered over the past few years. In this group, patients sustained comparable prefrontal damage in early childhood, rather than as adults. As they developed, these children were cognitively normal in the traditional IQ sense, able to use logical reasoning and factual knowledge to solve the kinds of academic problems expected of students. However, while smart in the everyday sense of the word, these children slowly revealed themselves as having varying degrees of psychopathic and antisocial tendencies. They were insensitive to punishment and reward and did not seek approval or social acceptance as typical children do. As adults, they were unable to competently manage their lives, wasting time and squandering resources and engaging in dangerous, antisocial, and aggressive behaviors. By outward appearances, these patients behaved in most ways similarly to the patients described above, who sustained prefrontal damage as adults (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Damasio, 2005).

Additional investigation of adult patients with childhood onset of brain damage, though, revealed an intriguing difference between childhood and adult-onset prefrontal brain damage. While both groups can reason about traditional cognitive problems in the structure of the laboratory setting and both have normal IQs in the traditional sense, unlike patients with adult-onset prefrontal damage, childhood-onset patients appear never to have learned the rules that govern social and moral behavior. While adult-onset patients know right from wrong in the lab but are unable to use this information to guide their behavior, childhood-onset patients have apparently not learned right from wrong or the proper rules of social conduct. They do not know the social and ethical rules that they are breaking.

What is happening with these patients and how is it relevant to the argument at hand? Unlike the often remarkable compensation for linguistic and other capacities after early childhood brain damage, so far the system for social conduct and ethical behavior does not show this kind of compensation. It is not that access in an abstract sense to the rules of social conduct requires intact frontal cortices, as the adult-onset patients show, and it is not that a social or moral conduct center in the brain has been irreparably damaged, as this scenario would not explain changes in general decision making. Instead, the situation is both simpler and more grave. These early-onset prefrontal patients may be suffering from the loss of what we might term the *emotional rudder*. Without the ability to manipulate situations and to mark those situations as positive or negative from an affective point of view, these children fail to learn normal social behavior. In turn, they lose the commensurate decision-making abilities described earlier. Insensitive to others' responses to their actions, these children fail to respond to educators' and others' attempts to teach them normal behavior.

But there is another intriguing piece to be learned from these children regarding the relationship between cognition and emotion and the role of the emotional rudder in learning. As in the adult-onset patients, it is still possible for these patients to have an operating cognitive system that allows them to be smart on certain measures and in certain contexts, solving standard cognitive tasks in a laboratory or structured educational setting without difficulty. In these contexts, their lack of knowledge is confined to the social and moral domains.

And yet, once outside of the structured school setting, their social deficits manifest as a much broader problem. They have the nonsocial knowledge they need, but without the guiding effects of the emotional rudder, they cannot use this information to guide their everyday living, even in nonsocial contexts. What these patients confirm is that the very neurobiological systems that support emotional functioning in social interactions also support decision making generally. Without adequate access to social and cultural knowledge, these children cannot use their knowledge efficaciously. As Vygotsky posited more than three quarters of a century ago, social and cultural functioning actually does underlie much of our nonsocial decision making and reasoning. Or, more precisely, social behavior turns out to be a special case of decision making and morality to be a special case of social behavior (see Damasio, 2005, for a more complete treatment of this argument). The neurological systems that support decision making generally are the same systems that support social and moral behavior. Without adequate access to emotional, social, and moral feedback, in effect the important elements of culture, learning cannot inform real-world functioning as effectively.

A Physiological and Evolutionary Account of Emotion and Cognition: From Automatic Responses to Morality, Creativity, High Reason, and Culture

In the perspective of the insights described earlier, and of much research in neurobiology and general biology in the two intervening decades, the connection between emotion and cognition is being seen in a very different light. To outline the current position, we shall present a simple scenario. Think of an ant crawling along a sidewalk, carrying a piece of food back to its nest. The ant scurries into a sidewalk crack to avoid being stepped on, then continues industriously on its way. What motivates this ant to preserve its own life? How did it decide, albeit nonconsciously and automatically, to carry the piece of food and to turn toward its nest? Clearly, the decisions to hide to avoid being crushed, to carry the food, and to continue in the direction of the nest are primitive instances of cognition, composed of complex packages of innate responses that enable the ant to react advantageously to particular classes of situations. But what is essential to understand is that these and myriads of other primitive examples of cognition, even in the lowly ant, act together in the service of an emotional goal: to maintain and promote homeostasis and thus fitness. In short, the ant behaves the way it does because those behaviors promote its survival and efficiency. (Humans, as conscious beings, perceive that efficiency as well-being and pleasure.) Every action the ant takes is inherently biased toward helping the ant, or its group, do well.

Taking an evolutionary perspective, even the simplest unicellular organism has within the nucleus of its cell a master controller that permits that living organism to maintain itself for a certain span of life and to seek during that period the conditions that will allow it to thrive. Emotions and the mechanisms that constitute them as behaviors, which humans experience as resulting in punishment or reward, pain or pleasure, are, in essence, nature's answer to one central problem, that of surviving and flourishing in an ambivalent world. Put simply, the brain has evolved under numerous pressures and oppressions precisely to cope with the problem of reading the body's condition and responding accordingly and begins doing so via the machinery of emotion. This coping shows up in simple ways in simple organisms and in remarkably rich ways as brains get more complex. In the brains of higher animals and people, the richness is such that they can perceive the world through sensory processing and control their behavior in a way that includes what is traditionally called the mind. Out of the basic need to survive and flourish derives a way of dealing with thoughts, with ideas, and eventually with making plans, using imagination, and creating. At their core, all of these complex and artful human behaviors, the sorts of behaviors fostered in education, are carried out in the service of managing life within a culture and, as such, use emotional strategies (Damasio, 1999).

Emotion, then, is a basic form of decision making, a repertoire of know-how and actions that allows people to respond appropriately in different situations. The more advanced cognition becomes, the more high-level reasoning supports the customization of these responses, both in thought and in action. With evolution and development, the specifications of conditions to which people respond, and the modes of response at their disposal, become increasingly nuanced. The more people develop and educate themselves, the more they refine their behavioral and cognitive options. In fact, one could argue that the chief purpose of education is to cultivate children's building of repertoires of cognitive and behavioral strategies and options, helping them to recognize the complexity of situations and to respond in increasingly flexible, sophisticated, and creative ways. In our view, out of these processes of recognizing and responding, the very processes that form the interface between cognition and emotion, emerge the origins of creativity—the artistic, scientific, and technological innovations that are unique to our species. Further, out of these same kinds of processing emerges a special kind of human innovation: the social creativity that we call morality and ethical thought.

As the childhood-onset prefrontal patients show, morality and ethical decision making are special cases of social and emotional functioning. While the beginnings of altruism, compassion, and other notions of social equity exist in simpler forms in the nonhuman primates (Damasio, 2003; Hauser, 2006), human cognitive and emotional abilities far outpace those of the other animals. Our collective accomplishments range from the elevating and awe inspiring to the evil and grotesque. Human ethics and morality are direct evidence that we are able to move beyond the opportunistic ambivalence of nature; indeed, the hallmark of ethical action is the inhibition of immediately advantageous or profitable solutions in the favor of what is good or right within our cultural frame of reference. In this way, ethical decision making represents a pinnacle cognitive and emotional achievement of humans. At its best, ethical decision making weaves together emotion, high reasoning, creativity, and social functioning, all in a cultural context (Gardner, Csikszentmihaly, & Damon, 2001).

Returning to the example of the ant, our purpose in including this example was not to suggest that human emotions are equivalent to those of the ant or that human behavior can be reduced to simple, nonspecific packages that unfold purely nonconsciously in response to particular situations. Although some aspects of human behavior and emotion could be characterized in this way, such reductionism would be grossly misplaced, especially in an essay about connections to education. Instead, we aimed to illustrate that most, if not all, human decisions, behaviors, thoughts, and creations, no matter how far removed from survival in the homeostatic sense, bear the shadow of their emotive start.

In addition, as the prefrontal patients show, the processes of recognizing and responding to complex situations, which we suggest hold the origins of creativity, are fundamentally emotional and social. As such, they are shaped by and evaluated within a cultural context and, as we described in the previous section, are based upon emotional processing. No matter how complex and esoteric they become, our repertoire of behavioral and cognitive options continues to exist in the service of emotional goals. Neurobiologically and evolutionarily speaking, creativity is a means to survive and flourish in a social and cultural context, a statement that appears to apply from the relatively banal circumstances of daily living to the complex arena of ethical thought and behavior. In beginning to elucidate the neurobiological interdependencies between high reasoning, ethics, and creativity, all of which are fundamentally tied to emotion and critically relevant to education, we hope to provide a new vantage point from which to investigate the development and nurturance of these processes in schools.

Emotional Thought: Toward an Evidence-Based Framework

In general, cognition and emotion are regarded as two interrelated aspects of human functioning. However, while it is perfectly reasonable and in fact necessary to distinguish between these two aspects in studying learning and development (Fischer & Bidell, 1998), the overly stringent preservation of this dichotomy may actually obscure the fact that emotions comprise cognitive as well as sensory processes. Furthermore, the aspects of cognition that are recruited most heavily in education, including learning, attention, memory, decision making, motivation, and social functioning, are both profoundly affected by emotion and in fact subsumed within the processes of emotion. Emotions entail the perception of an emotionally competent trigger, a situation either real or imagined that has the power to induce an emotion, as well as a chain of physiological events that will enable changes in both the body and mind (Damasio, 1994). These changes in the mind, involving focusing of attention, calling up of relevant memories, and learning the associations between events and their outcomes, among other things, are the processes with which education is most concerned. Yes, rational thought and logical reasoning do exist, although hardly ever truly devoid of emotion, but they cannot be recruited appropriately and usefully in the real world without emotion. Emotions help to direct our reasoning into the sector of knowledge that is relevant to the current situation or problem.

In Figure 1, we provide a graphical depiction of the neurological relationship between cognition and emotion. In the diagram, we have used the term emotional thought to refer to the large overlap between cognition and emotion. Emotional thought encompasses processes of learning, memory, and decision making, in both social and nonsocial contexts. It is within the domain of emotional thought that creativity plays out, through increasingly nuanced recognition of complex dilemmas and situations and through the invention of correspondingly flexible and innovative responses. Both the recognition and response aspects of creativity can be informed by rational thought and high reason. In our model, recognition and response processes are much like the concepts of assimilation and accommodation proposed by Piaget (1952, 1954). However, Piaget focused almost exclusively on cognition and the development of logic, and although he recognized a role for emotion in child development (Piaget, 1981), he did not fully appreciate the fundamentally emotional nature of the processes he described.

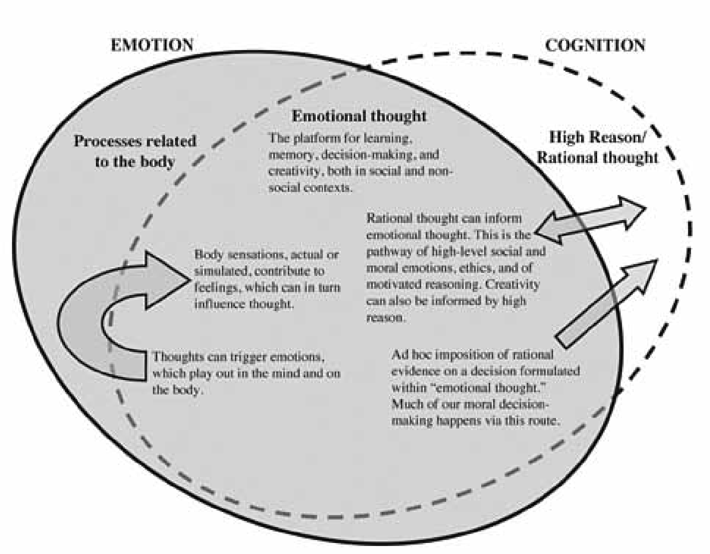

Fig. 1: The evolutionary shadow cast by emotion over cognition influences the modern mind. In the diagram, the solid ellipse represents emotion; the dashed ellipse represents cognition. The extensive overlap between the two ellipses represents the domain of emotional thought. Emotional thought can be conscious or nonconscious and is the means by which bodily sensations come into our conscious awareness. High reason is a small section of the diagram and requires consciousness.

In the diagram, high reason and rational thought also contribute to high-level social and moral emotions to form the specialized branch of decision making that is ethics. Motivated reasoning works in a similar manner and refers to the process by which emotional thoughts gain additional significance through the application of rational evidence and knowledge. In the other direction, rational evidence can be imposed upon certain kinds of emotional thought to produce the sort of automatic moral decision making that underlies intuitive notions of good and evil (Greene, Nystrom, Engell, Darley, & Cohen, 2004; Greene, Sommerville, Nystrom, Darley, & Cohen, 2001; Haidt, 2001). For example, in evaluating the morality of incest, experimental evidence suggests that people decide quickly at the subconscious and intuitive level and later impose ad hoc rational evidence on their decision (Haidt, 2001). Conversely, complex moral dilemmas such as whether to send a nation to war are (one hopes) informed by an abundance of rational evidence.

On the left side of the diagram, the bodily aspects of emotion are represented as a loop from emotional thought to the body and back. Here, emotional thoughts, either conscious or nonconscious, can alter the state of the body in characteristic ways, such as by tensing or relaxing the skeletal muscles or by changing the heart rate. In turn, the bodily sensations of these changes, either actual or simulated, contribute either consciously or nonconsciously to feelings, which can then influence thought. (Simulated body sensation refers to the fact that sometimes imagining bodily changes is sufficient; actually tensing the fists, for example, is not necessary.) This is the route by which rational deliberations over, say, a nation's wartime decisions can produce high-level social emotions such as indignation, as well as the bodily manifestations of these emotions, such as tensed fists, increased heart rate, or loss of appetite. The feeling of these bodily sensations, either consciously or not, can then bias cognitive processes such as attention and memory toward, in this case, aggression. The end result may be an unprovoked argument with one's friend over a topic totally unrelated to the war, the creation of a bleak and angry abstract painting, or a generally tense mood.

In addition to the evidence discussed above, support for these relationships between the body, emotion, and cognition comes mainly from neurobiological and psychophysiological research, in which the induction of emotion, either directly by a stimulus in the environment or indirectly via thoughts or memories, causes mental changes as well as physiological effects on the body. In turn, feelings of emotion rely on the somatosensory systems of the brain. That is, the brain areas associated with interoception (the sensing of body states) are particularly active as people feel emotions such as happiness, fear, anger, or sadness (Damasio et al., 2000).

To conclude, in presenting this model, our goal is not to devalue established notions of cognition and emotion but to provide a biologically based account of this relationship and to begin to specify the nature of the overlap between cognition and emotion in a way that highlights processes relevant to education. These processes include learning, memory, decision making, and creativity, as well as high reason and rational thinking. They also include the influence of the mind on the body and of the body on the mind.

Educational Implications: A Call for Further Research

In teaching children, the focus is often on the logical reasoning skills and factual knowledge that are the most direct indicators of educational success. But there are two problems with this approach. First, neither learning nor recall happen in a purely rational domain, divorced from emotion, even though some of our knowledge will eventually distill into a moderately rational, unemotional form. Second, in teaching students to minimize the emotional aspects of their academic curriculum and function as much as possible in the rational domain, educators may be encouraging students to develop the sorts of knowledge that inherently do not transfer well to real-world situations. As both the early- and late-acquired prefrontal damage patients show, knowledge and reasoning divorced from emotional implications and learning lack meaning and motivation and are of little use in the real world. Simply having the knowledge does not imply that a student will be able to use it advantageously outside of school.

As recent advances in the neurobiology of emotions reveal, in the real world, cognition functions in the service of life-regulating goals, implemented by emotional machinery. Moreover, people's thoughts and feelings are evaluated within a sociocultural context and serve to help them survive and flourish in a social, rather than simply opportunistic, world. While the idea that learning happens in a cultural context is far from new (Tomasello, Carpenter, Call, Behne, & Moll, 2005), we hope that these new insights from neurobiology, which shed light on the nested relationships between emotion, cognition, decision making, and social functioning, will provide a jumping-off point for new thinking on the role of emotion in education. As educators have long known, it is simply not enough for students to master knowledge and logical reasoning skills in the traditional academic sense. They must be able to choose among and recruit these skills and knowledge usefully outside of the structured context of a school or laboratory. Because these choices are grounded in emotion and emotional thought, the physiology of emotion and its consequent process of feeling have enormous repercussions for the way we learn and for the way we consolidate and access knowledge. The more educators come to understand the nature of the relationship between emotion and cognition, the better they may be able to leverage this relationship in the design of learning environments.

In conclusion, new neurobiological evidence regarding the fundamental role of emotion in cognition holds the potential for important innovations in the science of learning and the practice of teaching. As researchers struggle with new directions and techniques for learning about these connections, a biological framework may help to constrain possibilities and generate new hypotheses and research directions. Just as neuroscience is coming to inform other education-related topics and problems (Goswami, 2006), the study of emotions, creativity, and culture is ripe for interdisciplinary collaborations among neuroscientists, psychologists, and educators. After all, we humans cannot divorce ourselves from our biology, nor can we ignore the high-level sociocultural and cognitive forces that make us special within the animal kingdom. When we educators fail to appreciate the importance of students' emotions, we fail to appreciate a critical force in students' learning. One could argue, in fact, that we fail to appreciate the very reason that students learn at all.

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Musings on the Neurobiological and Evolutionary Origins of Creativity via a Developmental Analysis of One Child's Poetry

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with Nora Ming-Min Yang

As Antonio Damasio and I discuss in the article, "We Feel, Therefore We Learn: The Relevance of Affective and Social Neuroscience to Education" (*MBE*, 2007), all human thoughts and actions, and especially creative or innovative thoughts and actions, bear the shadow of the brain's original, evolutionary purpose—to keep one's body alive and functioning comfortably, efficiently, and appropriately in the world. Although neuroscience may simply confirm what experience has taught us, the evidence is plain. Our brains sense the insides of our bodies not only to regulate their mechanics, for example to adjust blood pressure and digestion appropriately to maintain our health, but also to play out the subjective, experiential dimensions of our social and emotional lives. We think something, consciously or not, and sometimes our brains adjust our physiology to reflect the emotional implications of that thought. Then, we may feel back the results of those embodied changes, as a source of information about our own reaction. Neuroimaging experiments show us that we use the very same neural systems to feel our bodies as to feel our relationships, our moral judgments, and our creative inspiration. We really do live by "gut feelings," and of course these gut feelings are induced and felt by our brains in accordance with our beliefs, experience, and knowledge.

And yet, you might ask, what sense does it make to put creativity on an equal footing with survival? How, for example, could anyone find comfort and efficiency in crawling into a damp black cave in southern France to spit chewed pigments on entombed rock faces in patterns portraying wild beasts? Or how could a contemporary human find fulfillment in gazing at a gibbous moon on a clear night, wondering about the other side and what the view from there might be like, staring off into the blackness of space? And aside from how humans could do these things, *why* do we feel compelled to do them?

The short answer is that, as we became the most socially interdependent mammals known to exist, the mechanisms we evolved to survive in the physical world seem to have been co-opted to manage our well-being in the social world. Survival in the savanna depends on a brain that is wired to make sense of the environment, and to play out the things it notices through patterns of bodily and mental reactions. Something catches our eye; we feel a jolt of adrenaline. Is that a poisonous snake or a vine? This same brain, the same logic, helps us make sense of and survive in the social world of today. Does that look on my teacher's face suggest displeasure or approval? Will this poem I have written convey to others the essence of my experience? With all the inter-relating and mind-reading and empathizing that we do with each other, and even with the moon when we so indulge ourselves, comes a drive to express ourselves, to understand and move others to live something from our own life, to assign meaning and purpose to the activities we engage in, the products we create, and the concepts we learn. The health of our social identity is every bit as important as our physical well-being because we *feel* them both on the same neural platforms. Why did that cave painter slither along that dank rock on his belly in the dark? Perhaps it had something to do with the satisfaction that comes from immortalizing one's own experiences, from affirming one's self by representing the feelings and thoughts witnessed by that self for someone, sometime, to see. After all, behind every painting or poem or essay or physics equation is a painter, a poet, a writer, a physicist. A real person, alive in both the biological and sociocultural senses, who is hoping to influence others' understanding by virtue of representing her own. What current neuroscience findings are showing us is that the feeling of creating, the satisfaction it provides, may get its inspirational power by virtue of its connections to the mechanisms that promote and feel our bodily survival and satisfaction, in the most basic, literal sense.

The poems included here provide an anecdotal but instructive example of how one child's developing understanding of the physical and social worlds are intertwined as she creates, just as they must have been for that mysterious cave painter from long ago. These poems were written on her own, just because she wanted to write them. You might even assert that she was *compelled* to write them, by virtue of the evolutionary origins of her modern, social mind. Because just like all humans before this young author, and all who will come, what social and affective neuroscientific studies are revealing is that the legacy of our intelligent brain is our social mind. By virtue of its evolutionary connection to bodily feeling and survival, our social mind motivates us to create things that represent the meaning we have made by processes of noticing, feeling, and understanding, so that others can notice and feel and understand what we have. While of course our bodies can no sooner live without food and water and warmth than they ever could, food, water, and warmth alone are no longer sufficient for us. Our biological drives are co-opted over the course of cognitive development into a platform for making sense of the world in increasingly complex ways. We must *understand*, we must *know*, we must *share* our experiences. What follows is an analysis of one girl's maturing attempt to do these things.

Poem 1. Untitled, Age 6 Years, 2 Months.

> Oh Teddy we love you mor then the whole rth sis as the rth spins evry day we love you as much as u shewell but sum timse evine mor as you mac us proud and happy tha chyr you!
>
> [Oh Teddy we love you more than that whole Earth Size. As the Earth spins every day we love you as much as usual, but sometimes even more, as you make us proud and happy that you're you!]

This poem was written as a song, with a melody, and was accompanied by a drawing of the author with a music stand singing to her brother, Teddy. What I love about this poem (song) is that it demonstrates so nicely the interdependence of emotion and even rudimentary disciplinary knowledge in learning. How does this little girl express the love and pride of her family for her little toddler brother—the love that she feels both biologically and socially? She references her newly acquired, simple knowledge of planetary science. She likens the vastness of her feelings to the size of the biggest thing she can think of—the Earth, and the endurance of the family's love over time to the constancy of the Earth spinning to make days. In the end, this is both a poem about a family's love for their baby, and one about the author's understanding of the planet she lives on.

Fig. 1: Poet's artwork

Poem 2. Age 7 Years, 3 Months.

Universe

The stars are floating around the earth.
As the earth looks so peasfull,
there are no wars right now,
and rainbows are shining as the clowds are mooving.
What a butifull sight.

The end.

In this poem, the author treats us to a vision of the world, observed from the perspective of the stars. As in the first poem, her descriptions of the planet are imbued with social emotions about the value of peace. From a developmental perspective, though, the author has gained a more complex ability to represent multiple ideas at once, as well as a clearer literary structure for the poem (that is, she frames the poem between a title and a closing). She presents us with one "beautiful sight" but grounds her idea in several pieces of evidence, all simultaneously true: the lack of wars, the shining rainbows, and the moving clouds. She titles the poem using the grandest concept she can think of, and, just as poets have for generations, she turns to her rudimentary knowledge of astronomy for inspiration.

Poem 3. Age 8 Years, 10 Months.

Let Love Flow Through You
(a poem for January)

There is a child
snuggled down for a good winter nap
Let him sleep peacefully
Let him blink silently
Let his mother's love flow through him
Don't wake him

This poem was written as part of a book that included one poem for each month of the year, given to the author's mother as a holiday present. In this poem, the first in the series, the author writes of a sleeping child. She takes the perspective of an omniscient onlooker, instructing the reader not to disturb the child's slumbers because even this simple action of sleeping is permeated with evidence of the child's close relationships—his mother's love flowing through him. Interestingly, the author titles the poem with a command to the reader, as if she can now mentally represent that her poems have a purpose—they can communicate her ideals to another person, the reader, and teach a lesson in the process. Her command of language is improving also, demonstrated by the alliterative repetition of the word "let" in the parallel structure of the middle lines.

Poem 4. Untitled, Age 9 Years, 5 Months.

Growing things are everywhere
and every day brings a new life
to Earth
which grows
and grows
until it reaches
its full height
it takes a last breath
and lies down
a new life
is born

In this final poem, the author connects her recurrent theme of Earth to her understanding of life and the life cycle. She returns to the idea she first presented earlier in poem 1, but with a new cognitive ability to represent systems of ideas, recurring in patterns. Whereas at age 6 she could relate one grand idea (strong and enduring love for her brother) to another grand idea (the Earth spinning over time), here she can understand that many smaller processes come together to make a bigger cycle. This cycle also invokes more complex emotional consequences for the reader than the earlier poems do, starting with a celebration of growing things, passing through the process of dying, and returning to the hopefulness of new life. She accomplishes this increased emotional complexity also through her developing sense of structure, going beyond the conventional framing she used in poems 2 and 3 and instead chopping her phrases with line breaks and indents to mark new, impactful ideas.

In conclusion, to tie these poems together, we can see that they exemplify nicely the role of what Antonio Damasio and I termed "emotional thought" in the accompanying article. Even the most dry and concrete factual knowledge about the world, for example facts about the workings of the physical planet on which we live, gains power when it is connected to this young author's social and emotional relationships and values. Her disciplinary knowledge of science becomes a source of metaphors for understanding and describing the social world, as well as the other way around—she uses the familiar feelings of social bonds to understand and appreciate the natural world. As she grows and builds more and more abstract disciplinary knowledge, knowledge that is separate from her social relationships, perhaps the childhood connections she once felt between her understanding of the physical world and the social experience of living on it will remain a source of inspiration.

Notes

All poems are written by Nora Ming-Min Yang.

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Nora Ming-Min Yang is a fourth grade student living with her mom, dad, and little brother in Southern California. She is a budding poet, pianist, and yogi who loves playing with her friends, hiking and camping with her family, and competing on a Girl Scouts robotics team.

LINK TO:

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Designing a Robot's Brain: An In-Class Learning Task

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ABSTRACT

In this article I discuss a learning task adapted for the college classroom in which students learn about the parts and functions of the brain by designing a robot's brain. This task is based on a four-phase model (engage, inform, practice, and feedback) of instructional design outlined by McAlpine (2004). I describe the four phases in relation to this learning task and provide samples of student feedback. I conclude with a discussion of how this model maximizes student learning.

Introduction

Over the past few decades, researchers have outlined the rapid and steady decline in student attention that occurs during extended lectures (Gibbs, Habeshaw, & Habeshaw, 1987; Silberman, 1996). Furthermore, Fink (2003) provides evidence that lectures are limited in their capacity to help students retain and transfer information and engage in higher-order thinking skills. The paradigm shift in higher education from a focus on content-centered instruction to learner-centered instruction (Barr & Tagg, 1995) highlighted the importance of involving students in the learning process. Attention and subsequent learning are enhanced when students are engaged in the task, when they perceive it as meaningful, and when they are given the opportunity to practice new material and to contextualize it. Active methods of teaching and learning satisfy many of these criteria and have been shown to promote both learner retention and transfer of information (Svinicki & McKeachie, 2011). According to cognitive scientists, the more engaged the student is with the learning task and the more he or she seeks to extract personal meaning from it, the greater the likelihood that underlying brain structures will change to promote learning that lasts (Leamnson, 2000).

Ramsden (1992) refers to this process of student engagement as adopting a deep, as opposed to a surface approach to learning. The author points out however that a student's approach to learning is not a characteristic of the individual learner but rather a function of how the learning task has been structured and what the student is being asked to do. It is therefore incumbent upon teachers to design instructional tasks that are meaningful for students and that will encourage them to adopt a deeper, more holistic approach, as opposed to a segmented, surface approach to learning. Fink (2003) and Whetten (2007) point out however that the area of course design represents the greatest challenge for teachers in higher education, as many lack the tools necessary to restructure teaching and learning activities that will bring about the significant learning experiences they desire for their students.

One noteworthy model of instructional design for higher education has been described by McAlpine (2004). This model, which is based upon contemporary theories of learning and Gagné's (1985) conditions of learning, outlines a framework for both instruction and learning that consists of four phases. During the first phase the teacher seeks to engage student attention by emphasizing the relevance of the learning task. The purpose is to encourage student motivation and to foster a deep approach to learning. During the second or informing phase, learners are presented with relevant background information. The third or practice phase is by far the most important part of the model. During this phase, learners "construct understanding and integrate knowledge in order to later retrieve and apply it at appropriate times" (McAlpine, 2004, p. 128). The author also maintains that during the practice phase, a learning environment which includes both structure and formative feedback will promote a deep approach to learning. The final phase of formal summative grading should mirror what students were asked to do during the practice phase. McAlpine provides general anecdotal evidence from teachers and students who attest to the efficacy of this model. In this article I provide an example of a learning task which extends this model to the CEGEP classroom. I also provide, through student feedback, evidence of learning throughout the four phases of engaging, informing, practice, and feedback.

Rationale

Introduction to Psychology is a compulsory course for all Quebec CEGEP (preuniversity) students who are enrolled in the Social Science Program. One of the modules in this course focuses on the human brain and its impact on behavior. This module partially meets one of the Ministry of Education's major learning outcomes for this course, which is to describe the biological, cognitive, and affective processes that underlie human behavior.

Most introductory psychology textbooks divide the human brain into three major sections: the lower brain or brainstem, the middle brain or limbic system, and the upper brain or cerebral hemispheres (Wood, Wood, Boyd, Wood, & Desmarais, 2011). There are approximately 30 different parts of the triune brain for students to master. Many Social Science students have limited background in biology and report difficulty learning the various brain structures and their related functions. The objective therefore was to design a task that would simultaneously engage student attention and enable them to achieve the following learning outcome: identify the major structures and the related functions of each of the parts of the human brain.

Description of the Learning Task

Engaging student attention: In order to address this learning outcome, students are told that they will work in small teams of two or three students during class time, to build a robot's brain. Members of each team collectively decide what job or task they want their robot to accomplish. They then brainstorm a list of skills that their robot needs, in order to execute its job effectively. Generating a list of prerequisite skills is important as it provides students with a series of advance organizers. The brain parts they eventually select must be considered in light of these requisite skills, in order to enable their robot to carry out its function. The team also names its robot. Typically students are intrigued by the novelty of this learning task. Their engagement is enhanced by the fact that they are able to customize their robot. They are also informed that they will receive a group mark for their team product.

Our robot is going to be a soccer player. Its name is Ronaldobot. It needs to be quick, coordinated, have anticipatory abilities and the ability to process information while the body is under physical stress. (Jordan and Felix)

Our robot's name is Maid Robot. Its job is to complete our chores. To do so it needs to move skillfully, remember its tasks and respond to touch. (Josianne, Jessica, and Nivart)

Our robot's name is T-Pain II. It goes to our classes (especially our 8:00 classes), assimilates information by creating lyrics with important information and it sings this to us in the evening. In short, it teaches us! (Julie, Youssef, and Olivier)

Designing the Robot's Brain

Inform: This assignment stipulates that for each of the three major sections of the brain, each team must select two parts that will enable its robot to perform its task most effectively. Thus, each robot that is designed must be able to execute its task reasonably well with just six brain parts. While students are required to learn the various parts of the brain, this selection process encourages the team to closely consider the function of each chosen part in order to maximize the robot's capabilities.

Beginning with the lower brain, I describe the structure and related function of the various parts. This is done in a 15-20 minute interactive lecture accompanied by PowerPoint slides. During this time students take notes and ask questions as they consider the various parts in light of their particular robot's task.

Practice and feedback: Team members then collectively decide which two brain parts of the lower brain are most appropriate for their particular robot. They are required to name each part, to describe the function of the brain part, and to explain why their robot needs this specific component to carry out its task. Students are encouraged to refer back to their initial list of required skills (advance organizers) as they justify the selected brain part. They also consult their textbook and notes when completing this exercise. The practice phase of this learning task, during which students are engaged in group discussions and in making collective decisions about what material to include and why, is by far the most important part of the learning process. Verbalizing the information provides students with the opportunity to verify their understanding of concepts and to receive feedback from peers on their comprehension. While students confer with their team members, I walk around the classroom listening to discussions and offering suggestions and feedback. The formative feedback that I provide during this time sometimes leads group members to reconsider and perhaps alter their choices or to provide a more substantial justification for their particular selection. The discussions that ensue between teacher and students help to reduce the power differential as learning is viewed as an ongoing and collaborative process. Both peer discussions and student-teacher discussions provide students with an opportunity to engage with the material on a deeper level.

Our robot Ronaldobot needs a cerebellum. This part of the brain coordinates skilled movement, regulates muscle tone and posture, and plays a role in motor learning and posture (Wood et al., 2011). Ronaldobot will need his cerebellum because in order to be a good soccer player, it will require a vast array of technical skills and coordination, which are largely controlled by the cerebellum. (Jordan and Felix)

The same procedure of inform, followed by practice and formative feedback is carried out, for the following two major parts of the brain: the mid-brain or limbic system and the cerebral hemispheres.

Our robot, Maid Robot, needs a hippocampus. This part of the brain plays a central role in the formation of long-term memories. It also helps our brain form maps of space that allow us to learn our way around the environment and remember where we have been (Wood et al., 2011). The hippocampus will enable our robot to remember all of its chores and also to be able to find its way around the house. (Josianne, Jessica, and Nivart)

The occipital lobes contain the primary visual cortex where vision is first registered and the association areas that are involved in the interpretation of visual information (Wood et al., 2011). This part will be useful for Ronaldobot—it will need perfect vision to be able to anticipate every move on the field the players make. (Jordan and Felix)

Final assessment: At the end of this exercise, each team must judge whether or not its robot will be able to carry out its task with just six brain parts. This segment of the learning task encourages the team to not only consider individual parts and their function, but also to reflect on the relationships between the parts and the whole. As the student comments below reveal, some teams are more cognizant than others of the interdependency among brain parts.

Our robot will be able to carry out its task (doing our chores in the house) because it can move skillfully; it can remember its chores and how to do them and it can find its way around the house. (Josianne, Jessica, and Nivart)

It would be difficult for a human, let alone a robot, to function without all the parts of the brain. Although certain areas are specialized to perform particular tasks, it is the collective brain which allows us to function. As for individual sections, our robot Ronaldobot would need many additional parts not mentioned in this assignment such as the parietal lobes, which register touch, pressure, temperature, and pain. (Jordan and Felix)

Finally, each team reviews the assessment criteria before submitting its report. This verification encourages students to attend to the conditions upon which their work will be evaluated. Their robot assignment is then submitted for formal teacher assessment. There is a close match between what students are asked to do in this learning task and how they are subsequently assessed, for example, on class tests. The alignment between practice and assessment is key to the effective implementation of this model in terms of promoting learning and retention.

Advantages

There are several advantages to this learning task. First, all phases can be accomplished within a reasonable time frame (approximately two and a half hours of in-class time). This includes teaching the three major sections of the brain and setting aside time for each team to build its robot, while simultaneously providing students with formative feedback. The fact that the building or practice phase of this exercise is timed maximizes student time on task. As well, attention is enhanced throughout the lecture portion of this task, as students know they will have to do something with the material. Students achieve a deeper level of understanding when they are asked to apply acquired knowledge (Whetten, 2007).

This task also requires students to work cooperatively in a small group and to negotiate decisions collectively. This aspect of reciprocity, when situated within a well-structured learning task, increases learner motivation and responds to the social needs of students (Silberman, 1996). Students who might be reluctant to participate in class discussions do so within their small group. Peer feedback also serves as an important check on comprehension and can lead to significant cognitive outcomes, especially when carefully designed learning tasks are aligned with course outcomes (Svinicki & McKeachie, 2011). Finally, absenteeism is reduced since the team receives a group mark for its product. The fact that students must consult their course textbook, particularly when describing the function of each brain part, encourages them to view this resource as a valuable reference and repository of information. The final assessment wherein each team considers whether its robot will be able to carry out its task with just six brain parts raises interesting discussions and encourages students to reflect on the product they have created. Most importantly, students regard this learning task as fun and it helps them to master challenging course material.

In conclusion, the model described by McAlpine (2004) consisting of the four phases of engage, inform, practice, and feedback can be used to design instruction (both teaching and learning activities) inside and outside of class. As well, it can be adapted at various levels including a lesson, module, or course and across various domains. The in-class learning task *Designing a Robot's Brain* described in this article provides evidence of how this framework can be successfully integrated into a CEGEP classroom to teach challenging content. It highlights the importance of creating significant learning experiences for students wherein learning tasks are clearly aligned with course outcomes. Feedback from student work attests to the efficacy of this model of instructional design and suggests that it offers a good fit for today's learners.

Postscript

Some semesters I use an alternate form of this instructional activity in which I invite students to write an essay describing how they would design their robot's brain. The advantage of this latter learning task is that it provides students with the opportunity not only to learn about the structures and functions of the brain, but also to practice writing about psychology. In addition to producing a well-structured essay that includes an introduction, body, and conclusion, students are also expected to integrate APA in-text citations. This essay, which is typically assigned at the beginning of the semester, provides me with a writing sample for each student. This information enables me to identify early on any students who are experiencing difficulty with either the writing process or with the acquisition of content knowledge. I subsequently refer them for tutoring.

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Yearning for Words, Learning With Words: Poetic Ruminations

Carl Leggo, University of British Columbia

ABSTRACT
As a poet I am always seeking ecological interconnections amidst body, brain, language, knowing, mind, consciousness, education, imagination, heart, cognition, and spirit. In language play I hope to find my way to a purposeful pedagogy that acknowledges and honours how learning is always a holistic adventure in process and flux, an adventure of human becoming filled with wonder and mystery beyond the counting, but always abundantly available for courting with wild delight and desire.

> "My experience is not described or explained by language; it is language" (Griffin, 1995, p. 192).

In *Unleashing Your Language Wizards: A Brain-Based Approach to Effective Editing and Writing*, Crow (2010) observes that despite the significant time and effort that educators have invested in teaching writing, "many students still do not write very well" (p. ix). Crow presents a brain-based approach to teaching writing that emphasizes inquiry-based learning: "*Don't cover the material—let students* uncover *it*" (p. 41). I admire Crow's compelling vision of brain-based learning as: multimodal, hands on, problem solving, pattern based, interconnective, challenging, and recursive. Nevertheless, while Crow sustains a clear focus on grammar, registers, diction, punctuation, and voice in expository writing, I recommend that one more way to attend to the complex relationships amidst the brain and mind and education is to play with words and shapes and sounds in order to attend to the mysteries of denotation and connotation, syntax and semantics, in order to explore again and again how language is integrally connected to the heart of learning, and how the heart's yearning is to ask questions that might not have answers, all part of a quest to acknowledge how the world is full of mysteries and enchantments beyond the counting. As a poet I invite educators to ruminate on the possibilities of what Calvino (1995) calls a "pedagogy of the imagination" (p. 92).

Babble and Doodle

words as a perpetual pursuit
Italo Calvino

stretch words tight and taut so they twang
words wait between the lines to be called
these words, your words, more words, words

throw words in the air, seek shapes
words never let you go, always let you go
the world woven in the shadows of words

write the earth, one word after another
words open up expanding worlds
words, spoken here and there, for you

care about words, offered with care
words seek their way, light offered
the way into the haunted words

lay down words, linear and labyrinthine
words wind through the blood, no end
a parade of words, glad to be alive

laugh with wild words, dangers everywhere
words remember what can't be forgotten
words with the heart's beat, full of breath

host a surprise party for words
words don't always need punctuation
words, the hermeneut's heresy, a long quest

seek words that give you goose-bumps
words whisper secrets in shopping malls
scribbled words in gusts of wind

hold words tentatively, not with tentacles
words challenge grammar with glamour
words as a perpetual pursuit, full of yearning

… our language passes in at the eyes, out at the mouth, in at the ears; the words are immersed and steeped in the senses of the body before they make sense in the mind. They cannot make sense in the mind until they have made sense in the body (Berry, 1990, p. 192).

Body wisdom is not found in the mind or the spirit, but in the belly—the deep core of the body, where it signals with physical sensations what feels 'right' or 'wrong' to us: our gut feelings (Arrien, 2005, p. 73).

Cogito Ergo Sum

I think, therefore I am
I blink, therefore I am not
I wink, therefore I am naughty

I clink, therefore I am here
I sink, therefore I am where
I slink, therefore I am somewhere

I ink, therefore I am a blab
I fink, therefore I am a scab
I dink, therefore I am a drab

I drink, therefore I am pee pee
I stink, therefore I might (not) be
I kink, therefore I am a knot, not free

I plink, therefore I am ludic
I jink, therefore I am elusive
I wrinkle, therefore I am loosely

In European culture, the idea of logic, reason, even the capacity for insight, thought, or clear-mindedness have been situated so firmly in the duality between intellect and emotion, mind and body, spirit and matter that to challenge this duality must seem like a threat to consciousness itself (Griffin, 1995, p. 40).

… *a particular language leads the speaker down a particular thinking pathway* (Little Bear, 2004, pp. vii–viii).

Logical?

analogical
biological
chronological
dialogical
ecological
futurological
geological
horological
ideological
jumpological
kinological
logical
meteorological
neurological
ontological
phenomenological
quinological
radiological
sociological
tautological
ufological
virological
waxological
xenological
yesological
zoological

Doubtless the final state of thought is disorder, rambling, the fragment and extravagance (Baudrillard, 1997, p. 118).

There couldn't be a fragment that doesn't relate to everything (Lynch, 2006, p. 141).

Phony Euphony

ambling in ample academic addiction
        babbling bubbling bumptious boasts
cuddle coddle the challenge of change
        dazzle with a double dabble dribble
epistemologies & pissing mythologies
        fat flatulence filled with flat fraudulence
grumble with gregarious grubby greed
        humour a hidden hegemonic tumour
idols of ideology & idle ideologues
        jump the juvenile jumble of jouissance
keen kinetics knowing kissing kinetosis
        language languishes imitation limitation
message a massage in a messy mass age
        noxious notoriety with nervy nonsense
oblique obligations & obtuse openings
        peddle in prepositions & propositions
querulous quest for a queer question
        razzle rattle riddle ripple rubble rebel
sadistic statistics staked to mistakes
        tooting tottering in a tattered toupee
unaccountable ubiquitous ululation
        vandalized & analyzed & scandalized
writhing in writing & righting wrongs
        xenogenetic xylophonic xerophyte
yearning for yackety-yak on a yacht
        zealous zanies on the ziggurat zenith

Artist brain is associative and freewheeling. It makes new connections, yoking together images to invoke meaning (Cameron & Bryan, 1992, p. 13).

The mind that truly seeks treasures will go to the furthest place to hear the magic word that leads to them (Bloch, 2006, p. 107).

Art Arrests

hymn to voluptuousness, to the voluptuousness of writing – Hélène Cixous

art arrests   art attests   attuned attentiveness
          bonny lass with bony ass   alas   at last
circumambulatory criticism   cynical ceremony
          did Didymus bet on the alphabet   no doubt
eaves   dropping in the evening   ever even
          fail in the fall, fall in failing, flailing in failing
grab bag gabfest, more gumbo than gumption
          hyena   hyphen   hymen   a heaving heart
iron a shirt iron in the blood pumping irony
          joyful journey of just   juxtapositions
kind of kin   kindly kindled   kinship sailed
          lust is a must   bust a button, Philip Larkin
momentousness of the moment, not monumental
          naughty novice needs new night goggles
omnivorous orphans   ominous omens
          pearls   purls   perils   perles   perplexed
questioning   quetzals weary your query
          raining on the reindeer in romantic Rovaniemi
scoundrel in a scandal   wearing sandals
          taxi station   toxic taxing taxation   attending
uttering urgently uxorious understanding
          vivifying vivacious voluptuous verbs
words   how many words is Wordsworth worth
          Xeroxed ox   a tale of oxen or oxtail soup
yodeling yellow yeses   with yearning
          zombies   in zoot suits   suit the zoo

As a poet I am always seeking ecological interconnections amidst body, brain, language, knowing, mind, consciousness, education, imagination, heart, cognition, and spirit. In language play I hope to find my way to a purposeful pedagogy that acknowledges and honours how learning is always a holistic adventure in process and flux, an adventure of human becoming filled with wonder and mystery beyond the counting, but always abundantly available for courting with wild delight and desire.

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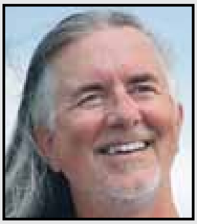

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Supporting Emotional Regulation in Elementary School: Brain-Based Strategies and Classroom Interventions to Promote Self-Regulation

Ann-Bailey Lipsett

ABSTRACT

Before students are able to be successful with academic demands they must be able to regulate their own emotions. Seven kindergarten students at a Title One school outside of Washington, DC participated in a small-group intervention in order to increase their ability to regulate their own emotions. The curriculum for this group was created based on the neurological implications of how the brain processes emotions.

"It's too hard!," Abagia, a kindergarten student groaned as I listened to my co-teacher introduce a new reading activity. "I can't do it! There is no way! I quit!" She hadn't even started the task yet, and knowing her abilities, my co-teacher and I were very confident she would have absolutely no difficulty accomplishing the task once she began. It was getting her to begin the task that was going to be challenging. We dismissed the students to their seats by calling out their shirt colors, and as "pink" was called Abagia groaned with agony. "OH NO" she moaned, "I'll NEVER be able to do this." She sat at her table and picked up her pencil to write her name. By this time her anxiety was in full swing and as she wrote *A* her pencil wobbled. Suddenly she was banging her hand into her head, "stupid, stupid, stupid" she cried. My co-teacher and I looked at each other. This was a typical morning with Abagia.

Like many of the students at our school Abagia is a second-language learner who entered the United States a month before she began kindergarten. We have no idea what she experienced in her war-torn country, or exactly what her day-to-day life was like in the five years before she entered our building. Our job now is to teach this smart, quick-witted yet anxiety-filled five-year-old to read, count, add, and subtract. Soon after meeting Abagia, however, we realized that before we could teach her any new skills we would need to help her override her anxiety. No matter how capable she is, there was no way she could achieve academic success in kindergarten if she could not use self-calming strategies to work through frustrating situations.

This is true for many of the students I work with at my diverse Title One elementary school, located just outside of Washington, DC. Before we can begin to teach content we need to ensure that our students are available for learning. To reach Abagia as well as seven other kindergarteners who also showed difficulty with emotional regulation I created an early morning social skills group using the structure for morning meetings described in the Northeast Children's Foundation's, *Morning Meeting Book* (Kriete, 2002). I relied heavily on my understanding of brain development, the regions in the brain that processes emotions, Gayle Macklem's (2010) book, *Practitioner's Guide to Emotional Regulation in School-Age Children*, as well as other texts dealing with emotional regulation in order to create a curriculum and a procedure for working with these seven students. Like most interventions in education the intervention did not solve all of Abagia's difficulties, yet it gave her and the six others a firm base in coping with their emotions in order to allow them to be available to learn in their general education kindergarten classrooms.

Understanding Emotional Regulation

The term emotional regulation rarely finds its way into conversations on education policy, school reform, or even best teaching practices. The pressing focus on academic demands leaves many teachers, principals, and policy makers overlooking the importance of imbedding the teaching of emotional regulation strategies into the curriculum. This leaves our youngest students, like Abagia, without methods for coping with their emotions, making it even more difficult for them to process academic information.

Gayle Macklem (2010), an educational psychologist, defines emotional regulation as how people are able to control which emotions are experienced, how and when they feel the emotions, and ways they express these emotions, both consciously and subconsciously. Emotional regulation comes into play not just in how a person expresses emotions, but in how a person is able to navigate through one's day, what stimulus he or she will attend to, how one interprets a situation, how one responds in situations, and in one's general functioning. In an academic setting poor emotional regulation can affect a child's ability to learn new material, interact with peers and adults, begin and complete tasks, and take tests. Poor emotional regulation can be seen in a child's impulsive behavior, procrastination, and difficulty with flexible thinking.

Three regions of the brain, the amygdala, the orbitofrontal area of the prefrontal cortex, and the hippocampus, all play a role in how emotion is processed (Gazzaniga et al., 2009). When one is presented with an environmental stressor the amygdala receives information indicating a threat. As Gazzaniga notes, the amygdala reacts by triggering both an automatic response of an increase in heart rate and blood pressure, as well as a behavioral response. A child can experience two types of reactions when met with fearful stimuli. If the child is reacting to previous memory he or she personally experienced the amygdala takes over due to its conditioned nature. A previously experienced threat will cause a child to react from experience. However, children can also react to a stimulus with fear or anxiety if they have been taught that the stimulus is a threat. In this situation the hippocampus memory system triggers the emotional response, signaling the amygdala to react and decide how to express the emotion. A child's prefrontal cortex controls the child's emotional recovery time, and is able to override the amygdala's reaction to a threat, giving the child control over inappropriate behavioral responses.

Importance of Emotional Regulation

Research shows that a child's emotional and behavioral regulation in preschool is a predictor of a child's social and academic competence in kindergarten (Bulotsky-Shearer, Dominguez, Bell, Rouse, & Fantuzo, 2010). Emotional regulation can be taught to children by directly teaching them strategies. This is particularly successful at times of school transitions, such as when entering kindergarten as well as the transition to middle school. Interventions have been found to be the most successful before age seven, although children are able to develop new skills after this time as well (Macklem, 2010).

Most children develop emotional regulation in the preschool years as they begin to develop language that allows them to label and express their own emotions as well as the emotions of others (Macklem, 2010). However, a child's temperament plays a large role in the development of emotional regulation, as does a child's interactions with his or her parents and his or her caretakers (Kagan & Snidman, 2004). A child's background including the family's socioeconomic status and the family's ability to handle and cope with stress all play a role in a child's development of emotional regulation (Dearing, 2010). A child's previous experiences influence how the child's hippocampus reacts to environmental stressors (Macklem, 2010). The hippocampus determines how a child will react depending on past experiences and associations stored in the child's memory. This hippocampus reaction leads to context-dependent emotional learning. Most likely, Abagia's background conditioned her hippocampus to react with heightened awareness and distress when presented with a novel situation, or in a situation where she is not guaranteed success.

Primary teachers can support the development of emotional regulation by simply talking about emotions, labeling them, and discussing and modeling strategies for coping with these emotions (Macklem, 2010). In her book, Macklem comments that this is true for parents as well. A child's interactions with parents and teachers have the greatest impact on a child's emotional regulation due to the amount of time they spend with these caretakers.

Emotional Regulation in the Classroom

It is essential for teachers to understand the role emotional regulation plays in a child's academic achievement and functioning in the classroom. Teachers have the power to create a positive classroom climate that allows for social and emotional skills to be taught alongside academic skills (Kauffman, 2005). However, most educators are not aware that teaching social-emotional skills will improve academic performance (Macklem, 2010). Simply managing classroom behavior in a manner that limits conduct problems is not enough to produce a change in children's emotional regulation.

In the early years it is particularly important for teachers to develop positive relationships with their students. These early relationships in school predict whether or not an individual will be able to self-regulate, develop relationships, and take different perspectives (Macklem, 2010). When children are presented with what they perceive as a stressful situation they experience a rise in cortisol. Prolonged or frequent rises in cortisol levels can damage hippocampus cells, impacting a child's long-term memory and ability to store new information for long-term retrieval. Research shows that children who experience poor relationships with their teachers in early grades are more likely to form fear-conditioned responses towards teachers and school within their amygdala that leads to automatic negative behavioral responses (Macklem, 2010). These automatic, neurological reactions developed early in a child's schooling will lead to task avoidance, weak cooperation in the classroom, and children who are less likely to be self-directed. Children who experience a trusting relationship with a teacher in the early years are more likely to engage freely in exploration, which gives them an appropriate base for learning academic and cognitive skills (Goldsmith, 2007). A study published by the National Research Council and Institute of Medicine (2000) found that children's relationships with their teachers in the early grades impacted how students viewed their school experience through eighth grade. This is particularly true of children who have poor relationships with their parents (Macklem, 2010).

Promising Approaches for Improved Results

Teachers can and should play a vital role in teaching and coaching children through learning and using strategies to help with emotional regulation (Rimm-Kauffman et al., 2009). Children are able to learn to control their emotional reactions by using the prefrontal cortex (Macklem, 2010). An emotional reaction can be reversed through practice and training when the prefrontal cortex is able to override the initial response within the amygdala. Children who would otherwise react to stimuli with fear or aggression are able to use their prefrontal cortex to react calmly and effectively. If a child's prefrontal cortex is activated during a stressful situation the child is more likely to recover quickly from negative emotions and stress. Once teachers understand their role in helping children gain control over their emotional regulation they are able to begin making steps within their classroom to help their students succeed.

Teachers need to have an understanding of the importance of labeling and discussing emotions, knowing how to react to temper tantrums, and need to have a variety of classroom-friendly cognitive behavioral therapy practices that can be used to teach strategies. Research shows it is essential these strategies are taught and practiced in the child's main classroom (Macklem, 2010). When emotional regulation strategies are taught in the classroom students are more likely to show improved behavioral control, peer social skills, and a decrease in withdrawn or off-task behaviors (Wyman et al., 2010).

Discussing Emotions in the Classroom

Teachers can facilitate a child's understanding and control of one's emotions simply by helping children label their emotions, identify what makes them angry, and learn strategies they can use when they experience particular emotions. By teaching children to label and identify emotions and emotional strategies teachers are able to help children respond to environmental stimuli with their prefrontal cortex instead of their amygdala. This gives children the ability to override the automatic fearful responses developed in the amygdala, leading to a decreased reaction time.

One technique that teachers can use to facilitate discussions about emotions is people watching (Macklem, 2010). Observing others from a distance or even watching sitcoms and labeling people's emotions can help children to identify different emotions and emotional reactions. Discussing why people react in different ways and determining whether or not their reactions are positive or negative will open the door to conversations about how a child can identify and regulate his or her own emotions. This will also help children begin to take other people's perspectives. Classroom teachers should frequently identify their own emotions, the emotions of characters in books, as well as help children identify their own emotions. By teaching "feeling" words and using them regularly teachers are able to give children the language they need to begin to own their emotions, allowing their prefrontal cortex to override their amygdala. Once children are able to identify their own emotions as angry or happy they can begin listing what causes them to experience these emotions. This allows children to become increasingly self-aware of how they interact in their own environment.

Once children are able to identify their own emotions as well as events that lead to these emotions they are ready to begin learning coping strategies. Helping a child to distinguish between the emotion and the action will begin to help the child feel control over his or her emotions. Children need to understand that it is alright to be angry when a friend takes their toy but that it is not alright to hit (Macklem, 2010). Teachers can identify problem-solving strategies to help children determine the best course of action once they feel angry. Creating prompt cards with these strategies on them, as well as rehearsing the strategies, will give children specific replacement behaviors for the negative actions, and will also aid their understanding of how they can control their actions and emotions. These strategies tie in the role of the hippocampus, creating memories the child can rely on in order to react to environmental stimuli.

Children also benefit from learning their own physical symptoms that are associated with their emotions. For instance, they may need direct instruction on how their body becomes tense when they are angry or how they have difficulty concentrating when they are worried. This can be done in correlation with intensity charting (Macklem, 2010).

Reacting to Strong Emotions in the School Environment

Children without strongly developed emotional regulation are more likely to act out in the classroom. Teachers need to understand the causes of the acting-out behavior as well as ways they can interact with the child to promote emotional regulating strategies (Crowe, 2009). A frequent strategy used by teachers is time-out, where a child is placed in a chair in the back of the room or in the hallway away from stimulation and the class. This strategy is often beneficial for the teacher and the other students, but sends a message of rejection to the child in time-out. In situations where a child with high anxiety and poor emotional regulation is placed in time-out away from anyone to help him or her regulate emotions, the child is likely to feel overwhelmed and frustrated (Goldsmith, 2007). This can lead to violent and destructive behavior. Instead of using time-out, teachers can utilize a time-in approach where they place the children in closer proximity to them. This allows the child to feel the adult's presence when he or she is calming down, aiding in his or her regulation. In the classroom this can be done by placing a chair closer to the teacher in the front of the room, yet slightly off to the side so that the child feels the teacher's presence but is not the center of attention.

How a teacher talks to children during times of heightened emotions is critical. A teacher who uses distraction techniques ("Here's a sticker!") will manage the behavior in the short term but will not help the child regulate emotions in the future. Instead a teacher can use language that promotes self-regulating such as, "It's time to calm down. You can think of something else" (Goldsmith, 2007). A teacher can also use problem-solving language such as, "Ask him if you can use it when you are finished."

When a child is upset it is essential to match a teacher's reaction with the child's temperament. Punishing overly anxious children in a punitive manner will only lead to further exciting them, and will not aid the student in calming down (Kagan & Snidman, 2004). For particularly anxious children it is important not to push them into situations where they do not feel comfortable—and equally important not to protect them from those same situations (Macklem, 2010). Instead a teacher can scaffold the child's exposure to the situation, allowing the student to know the teacher is there to support him or her, but that it is the child's job to manage the situation. Highly anxious children will react best when they are in new situations where they feel safe yet are encouraged to take risks.

Teachers conferencing one on one with an upset child need to use eye-to-eye techniques along with simple, non-threatening language (Goldsmith, 2007). They should acknowledge the child's emotion and offer strategies while maintaining a respectful physical distance. During this time teachers should monitor their body language, how they vary their facial expressions, and their tone of voice (Kauffman et al., 2006). Their conversations should be absent of judgment of the child and the behavior but instead should describe the behavior and end with briefly summarizing the conversation for the child (Crowe, 2009).

Reaching Abagia: Applying Emotional Regulation Teaching Practices

In hopes of giving Abagia strategies to regulate her own emotions, I formed a morning social skills group. Seven children in three different kindergarten classrooms were identified as needing emotional regulation strategies. Although research shows that interventions are best conducted in the child's main classroom, due to the academic demands and scheduling conflicts this was not possible at this time. Each teacher filled out a questionnaire on how the child reacted when upset, how frequently the child became upset, how long it took the child to return to task after being upset, and the type of language the child used when upset (Appendix A). Each teacher also identified a goal he or she would like to see the child accomplish. For five of the students teachers noted that they would like the child to use words or phrases to express emotions instead of grunting or pushing other children, while two were given goals to react to situations with the appropriate emotion.

The children attended a half-hour small-group session every morning for three weeks. Each session began with a brief morning meeting following the structure recommended by Responsive Classroom in order to build community and trust among the group members (Kriete, 2002). The morning meetings consisted of the children sitting in a circle, taking turns greeting one another using appropriate eye contact and language. Following the structured greeting group rapport was built through giving each student an opportunity to share something he or she was excited about or to answer a question of the day. The meeting ended with a short activity or game designed to help the children feel comfortable and have fun with their group members. After the morning meeting the group transitioned to the planned focus activity for the day.

The first week students created a common language by labeling emotions of characters in books, animal pictures (from *The Blue Day Book for Kids*, Grieve, 2005), and in themselves. They also worked to identify emotional triggers and distinguished between different degrees of emotions (e.g., a little sad, really sad, a little angry, really angry) while reading *Alexander and the Terrible, Horrible, No Good, Very Bad Day* (Voirst, 1972). The students modeled emotional reactions for one another and labeled each emotion. I spent time with the classroom teachers to make sure they understood the language that was being used in the small group so that it could be carried over into the classroom. I also spent time in each classroom throughout the day to apply the same language from the group to situations that arose in the classroom.

Once the group was able to label emotions we turned our focus toward how to react with appropriate emotional responses to situations. It had been noted that one of the students hit herself when angry, whether or not it was because she lost a crayon or she made a mistake on a paper. The group spent time each morning practicing tension-relieving practices such as tensing and relaxing arm muscles, doing wall pushups, and letting out deep breaths of air as though blowing bubbles. The group developed its own language for these activities so that the children were able to be prompted easily to apply these strategies when upset. The group read the book *Chicken Little* (Emberley & Emberley, 2010) and created a hierarchy of emotions from "the sky is falling" to "it is a beautiful day" (Macklem, 2010). The following day the group listed a range of activities that cause them to have emotions (playing with friends, not having anyone to play with at recess, losing a crayon, a hurt toe, an angry mother) and applied these reactions to the hierarchy chart in order to identify the appropriate emotions for each situation. (The group unanimously felt that having an angry mother was far worse than a hurt toe or sitting out at recess.) These exercises were intended to strengthen the connection between the amygdala's perception of environmental stressors and the prefrontal cortex's ability to control the reaction to the stressor. Close communication with the classroom teachers continued, as well as opportunities to carry over the language used in the small-group setting into the classroom.

In the third week the students role-played situations they viewed as stressful in order to practice using appropriate words and phrases in their emotional reactions.

They were then given tasks that would allow them to practice using these strategies (e.g., they were given difficult puzzles so that they could practice what to do when work seems too hard and were given a game where the teacher won so they could practice what to do when they lost a game). By practicing these situations it is hoped they developed both a memory in their hippocampus of what to do in a similar situation, as well as a plan in their pre-frontal cortex that would help override any immediate reaction their amygdala would otherwise signal.

During this project I found that in order to have a long-term impact on students' ability to regulate their emotions the focus must be not only on the students themselves but also on the communication between me and the classroom teacher. Educating the classroom teachers about the importance of teaching emotional regulating strategies, how to support these strategies in the classroom, and how to respond to difficult behaviors most likely will have a greater impact on the students than the small-group intervention itself. This communication was supported through frequent e-mails between the group leader and classroom teachers, opportunities to model language and strategies for the teachers, an informational packet explaining how to support emotional regulation in the classroom (Appendix B).

In the future I would like to create voice threads with the students in order to increase this common language across settings. The voice threads would be developed during the sessions and posted onto the school's on-line student newspaper for both parents and classroom teachers to view so that all adults who work with the children would be on the same page. Typically, when children publish voice threads they are excited to share their video projects with their teachers, peers, and parents. This ensures that their parents and teachers hear the language that had been introduced and would be able to coach their children in emotional situations to react appropriately. Due to scheduling conflicts and end-of-year testing we were unable to publish the voice threads we created this year.

Results

Anecdotal records show that all seven students appeared to increase their use of language in regards to emotions and were able to give examples of appropriate reactions for particular situations. However, whether or not they will continue to use this language once the group is no longer meeting is currently unknown as this group was conducted toward the end of the school year. In her classroom I observed Abagia becoming upset and then stopping herself, looking around the room for me, verbally labeling the strategies she needed to use, applying them, and moving on. She began seeking me out throughout her day to tell me when she used these strategies in the classroom. Although there were certainly times when her frustration got the best of her, the fact that she now has the language to express how she feels and the understanding that she can control her emotions and her environment is essential as the first steps in building her ability to regulate her emotions independently. Continued coaching as well as praise for when she uses these strategies will help her continue to make progress in regulating her own emotions. Other children in the group began to use simple words or gestures to express frustration instead of grabbing toys from other students, or withdrawing from peers. One girl in particular became especially savvy at naming her emotions and would tell her teachers that it was a "move to Australia day" when upset.

In the future I would like to repeat this small-group intervention again using a more formal data collection process that would note spontaneous emotional-regulation language use in the classroom before and after the intervention. Next year I hope to increase communication between classroom teachers and parents through voice thread and on-line publishing.

APPENDIX A

Date:
Student Name:
Teacher Name:

1. **Is the child able to identify emotions of herself/himself or others?**
   I.e.: Uses the language, "happy, sad, angry, mad" when looking at characters in books, or when talking about self.

   a. Not that I have observed
   b. Yes, but only about characters in books, not about peers or self
   c. Yes, about peers or characters in books, not about self
   d. Yes, when discussing self, characters, and peers
   e. Only when discussing self

2. **On estimate, how many times a day does the child become emotionally upset?**

   a. 0
   b. 1-2
   c. 3-5
   d. 6+

3. **How does the child react when upset?**

    a. Uses loud grunts or one-word phrases instead of language (i.e., "HEY" instead of "Excuse me, I was using that crayon")
    b. Withdraws from the group
    c. Cries
    d. Seeks adult attention
    e. Other (please explain):

4. **When you conference with the child is he/she able to use language to explain why he/she is upset?**
    (i.e., "I am sad because Jason will not sit beside me)

    a. Yes
    b. No

    If Yes, from your perspective is the child able to correctly identify what made him/her upset? (i.e., did Jason really not sit beside him/her, or did something else cause the child to become upset?)

    a. Yes
    b. No

5. **Do the child's emotional reactions seem age appropriate and match the situation?**

    a. Yes
    b. No

    If no, please give an example:

6. **How long does it typically take for the child to return to work after becoming upset?**

    a. Returns immediately after adult redirection
    b. 2-3 minutes
    c. 5 minutes
    d. Other (please explain):

7. **Is there any other information you would like me to know about the child's emotional reactions to stress?**

8. **What would you like to see the child gain from small-group intervention on emotional regulation?**

APPENDIX B

Teacher Information Packet

Theory and practice behind small-group emotional regulation intervention

Emotional Regulation

Emotional regulation can be defined as how people:

- control which emotions they experience
- how and when they feel emotions
- how they express emotions, both consciously and subconsciously

Emotional regulation determines how a person expresses emotions, navigates through the day, what stimulus he/she will attend to, how one interprets a situation, and how one responds to a situation.

In academic settings poor emotional regulation can affect a child's ability to:

- Learn and retain information
- Interact with peers and adults
- Begin and complete tasks
- Focus on task at hand

In the classroom this behavior manifests itself in:

- Impulsive behavior
- Procrastination
- Difficulty with flexible thinking

(Macklem, 2010)

NEUROLOGICAL BACKGROUND

Table 1
Three Regions of the Brain Play a Role in How Emotion Is Processed

Amygdala	• Responds when perceives stimulation as a threat • Triggers automatic response of increased heart rate and blood pressure • Triggers automatic behavioral response based on previous experiences (conditioned response)
Hippocampus	• Triggers a memory system response, telling the amygdala to react based on previously taught knowledge • Determines reaction based on past associations stored in child's memory • Context-dependent emotional learning
Prefrontal cortex	• Controls emotional recovery time • Can override or inhibit amygdala response to stimuli • Anticipates future outcomes to plan emotional responses • Training and practice gives logical response to stimuli as opposed to biological response • Key factor in self-control and self-regulation

Emotional Regulation and the Classroom

Early childhood teachers and parents play the greatest impact on a child's development of emotional regulation due to the large amount of time they spend with the child as caretakers. Research has shown that primary teachers' relationships with their students have a lasting impact on how children interpret school situations through the eighth grade (Macklem, 2010). This is particularly true of children who have poor relationships with their parents. Children who experience a trusting relationship with a teacher in the early years are more likely to engage freely in exploration, which gives them an appropriate base for learning academic and cognitive skills (Goldsmith, 2007). Teachers can promote positive emotional regulation simply by talking about emotions, labeling emotions, discussing and modeling strategies for coping with these emotions (Macklem, 2010).

Strategies

Labeling Emotions

Teaching children to label emotions, both the emotions of others as well as themselves, gives them language to use when processing emotional responses to stimuli.

- Use a common language when discussing emotions.
- Encourage children to label emotions as a way to understand their role in reacting to the environment.
- Observe and discuss the emotional reactions of others. Discuss why people react in different ways and whether or not these reactions are positive or negative.
- Identify your own emotions, the emotions of characters in books, and the emotions of the children in the classroom.
- Identify the stimulus that leads to an emotion.
- Identify and discuss physical reactions in children when they experience a particular emotion (tightened muscles, difficulty concentrating, and difficulty making eye contact) so that they become aware of their own biological responses to stimuli.
- Create a hierarchy of emotions and discuss and label the difference between being a little upset and really upset, or a little angry and really angry.
- Identify, model, and role-play appropriate reactions to stimulation.

Reacting to Strong Emotions in the Classroom

How teachers respond to children's behavior caused by poor emotional regulation has the ability to help or harm a child in the long term. Early childhood teachers have a significant impact on how children learn to regulate their emotions due to the time teachers spend with their students.

Table 2
Strategies for Dealing With Child's Behavior

AVOID…	TRY…
Time-out: Time-out sends a message of rejection to the child. Children with high anxiety and poor emotional regulation will feel overwhelmed and frustrated in a time-out setting. This can lead to violent and destructive behavior.	**Time-in:** Placing the child in proximity to the adult. The child is able to feel the adult's presence, which helps the child calm down and aids his or her self-regulation (Goldsmith, 2007).
Distraction techniques: Offering children a sticker when they are upset, or encouraging them to play with something else helps them in the short term but does not aid their ability to calm down on their own in the future.	**Language that promotes self-regulation:** When a child is upset use simple, direct language such as, "It is time to calm down." "Think of something else," "Ask him if you can use it when you are finished" (Goldsmith, 2007).
Punitive punishment for overly anxious children: Punitively punishing overly anxious children will further excite them, making it more difficult for them to calm down or learn to regulate their emotions in the future (Kagan, 2004).	**Match your reaction with the child's temperament:** Use non-threatening simple language, your physical presence, eye-to-eye techniques, to help a child become calm (Goldsmith, 2007). Acknowledge child's emotion, offer strategies while maintaining a respectful distance. Monitor your own body language, tone of voice, and facial expressions (Kauffman, 2006).
Banning a particular behavior: While our job is to keep children safe, simply telling them that they are not allowed to hit themselves when upset, kick a chair, or throw a pencil will not help them regulate this behavior in the future.	**Offer replacement behaviors:** Explain to the child that he or she may tighten and release his/her muscles when he/she feels angry, do wall pushups, or deep breathing exercises. These strategies should be taught when the child is calm and reasonable, and practiced frequently using simple language so when the child is upset the teacher may prompt him/her with a one- or two-word phrase as a reminder.

Table 3

Matching Adult Response to Child's Behavior*

CHILD'S BEHAVIOR	ADULT'S RESPONSE
Pre-tantrum	
Frowning, sighing, pulling away, fussing	Respond with suggestions, label the feelings, explain the cause of the feelings, offer problem-solving strategies.
Whining, complaining, demanding	Take a break, go for a walk with the child, encourage talking (just listen), offer to help find a solution, give an explanation, offer help.
Irritable, agitated	Give choices, give close attention, help to relax if allowed, validate feelings, offer your help.
Tantrum	
Arguing, yelling	Stay calm, speak very softly if at all, remind you are nearby and understand why the child is upset, indicate you are standing by to help.
Kicking, throwing	Move away, out of sight if possible but make sure the child is safe, remain calm.
Post-tantrum	
Crying	Help to relax, give positive assurance.
Sad	Support and reassure, remind the child that he or she can try again.
Seeking out support	Help to save face, offer options, begin problem solving, talk about how to make things better and how to deal with the emotions in the future.

*Table taken from the *Practitioner's Guide to Emotional Regulation in School-Aged Children* (Macklem, 2010, p. 56).

Note that the use of language with the child is mainly used in the pre-tantrum and post-tantrum stages. As the child's behavior escalates limit your use of language while maintaining your physical presence. Rationalizing behaviors, exploring choices and problem-solving strategies can be done before and after a tantrum. If a child is in the midst of a tantrum excessive language may further stimulate the child and will not help the child become calm.

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Using Brain Research and the Experience of Knitting Socks in Teacher Education

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ABSTRACT

This article is a self-study of the experience of introducing sock knitting as a course assignment for teacher candidates. The idea originated from a personal desire to easily turn a sock heel while dealing with dementia in an aging parent who once knit well. The adaptations this assignment have undergone are explained with regards to a personal ongoing study of brain research, reflections about teaching knitting, and students' comments about the challenges of learning to knit socks.

Introduction

Over a period of approximately two years, three seemingly unrelated events led me to create a teacher education course assignment centred upon knitting a pair of socks. Firstly, I was reminded of the emphasis Waldorf education places on knitting while attending the Tri-fold Applied Handwork Conference where I observed that most fellow attendees knitted as they listened to presentations. The curriculum that introduces knitting in kindergarten was explained, as was the reason that socks are knit in grade five. Samples of children's knitting were used to discuss the developmental needs of the child. In presentations, the founder of Waldorf education, Rudolf Steiner, was referred to, and his idea that "knitting is cosmic thinking" was emphasized. I returned home determined to find and complete my second pair of socks, which I had started knitting a decade earlier.

Trying to turn a heel was the second event that led me to consider knitting as an educational activity worthy of teacher candidates' undertaking. My frustration originated from my need to constantly count stitches and pay attention to tedious directions. In most other craft work, I usually catch on quickly, grasp the fundamental concepts, and begin adapting so I can create my own designs. I had already knit numerous sweaters, hats, and mitts with ease. My PhD dissertation involved examining handwork and is entitled "Craftmaking: A Pedagogy for Environmental Awareness" (MacEachren, 2001), yet I was not able to knit socks with ease. I was particularly bothered by the idea that I needed to follow a pattern when my grandmother's generation had not and they were far less schooled than me. My frustration led me to begin to deconstruct the challenges I was experiencing.

The third event, sadly, resulted from trying to understand my mother's Alzheimer's disease. I found myself explaining to her how to complete simple puzzles and practice memory games. This led me to examine the reasoning skills required to complete various types of activities. Witnessing my mother's deteriorating knitting ability, which resulted from no longer being able to follow directions for sweaters with fancy cable stitches and colourful designs, led me to wonder not just why she was losing her cognitive ability, but how had she learned to knit in the first place. It struck me that her ability to knit elaborate sweaters had always been based upon her dutiful conditioning of following line-by-line directions. In contrast, my craft interest was based upon dealing with problems of design and mastering the underlying concepts: in knitting socks, it was to understand the basis involved in making a heel. I wanted to reiterate the practice early knitters had gone through when they invented a way to turn a ninety-degree angle in a knitted tube shape. I shared these thoughts about my mother and my sock endeavour with a colleague who was a master knitter. She, too, found the ideas and connections captivating as she could not remember a time when she had depended upon a pattern. Her main area of research was critical theory. During our dialogue, she mentioned the work of Jean Anyon (1992), whose research explored how teachers in different socioeconomic neighbourhoods taught differently: teachers in lower economic neighbourhoods emphasized rote learning and seldom taught problem-solving skills. I continued to be puzzled about the connection between memory and problem solving versus rote learning.

Throughout these events, I had conversations with colleagues concerning our students' learning patterns. Initially my intrigue was focused upon each generation's learning styles. Then I recognized that the proliferation in technology was influencing the way a person learned. In the back of my thoughts were the ideas I had acquired from taking a one-day Brain Gym workshop and from reading Carla Hannaford's book *Smart Moves* (2005). Hannaford's ideas became part of one of my classes where I provided the rationale and explanation for why the complex movements involved in activities such as climbing developed a person's thinking skills. My explanations were stated in general ways and avoided all the neurological terms Hannaford uses.

As these seemingly unrelated activities had been occurring, I had proposed to teach a new course, had received acceptance, and so was now beginning to plan my classes. I was seeking experiential activities and assignments that could highlight integration across subject silos. By then I had completed knitting my socks. My new understanding of socks had originated from long conversations at many wool stores with staff who seemed intrigued by my questions about knitting directions and my ideas connecting Alzheimer's disease with design work. As well I had purchased various books in order to compare directions as I sought clear descriptions and illustrations. As I knit I also reflected. During these introspective moments, I felt as if I could almost feel new neural networks forming as my comprehension grew. I became quite confident that I could knit socks now for any size foot by depending only on the concepts I held in my brain; I had no need for a pattern as I understood the essential elements of sock and was adept at problem solving and making changes. As I concentrated and challenged myself to understand *socks* as a concept, I noted how problem solving and deep thinking seemed both invigorating and exhausting. Time passed quickly and without notice. In "eureka" moments of understanding, I felt as if I were exercising my neural network of gray matter. One day I started considering all the ways I could integrate "learning" if I required my students to knit socks as an assignment.

Knitting my own socks is one thing, but the challenges involved in teaching a classroom of teacher candidates to knit socks led to many more questions concerning the best way to teach such a complex activity. I experimented with creating a paper cutout of a sock and writing directions on it. I envisioned students assembling sequenced paper sections in order to be guided through the knitting process. Each part could be taped to the next part until a three-dimensional paper sock was assembled and served as a guide through the knitting process. It took me numerous attempts to actually make my envisioned sock model. Craft work seems to have an additional rigor to it as ideas cannot just be conceived and illustrated as in visual art; instead craft work requires knowledge to be demonstrated through the process of creating something that fulfills a function. I like the challenge of working in designs that require moving with relative ease back and forth between two to three dimensions, between paper and concrete form. I knew that many novice teachers lack the confidence to teach many math-related topics, such as volume and surface area, so I wondered if my paper cutout idea would aid or frustrate their comprehension. All of these ideas came together as I seriously considered whether knitting socks would be a suitable course assignment and would allow me to make subject connections. As an outdoor educator, I consider wool socks a necessary piece of outdoor equipment, and my first publication addressed the importance of socks to environmental education (MacEachren, 1990). I liked the idea that socks were common to students, but that few would know anything about their history or creation.

Course Parameters

The course I taught had the usual parameters that most university courses contain. My classes were scheduled for twice a week over just one term. This condensed format provided little time for me to introduce knitting skills and for students to complete their homework. In fact, many students required two weekends before even being able to visit a store to purchase their knitting supplies. As this assignment was weighted less than other assignments, knitting homework was not a high priority in their busy lives. Classes were two hours and twenty minutes long, with approximately 10-30 minutes devoted in each class to instruction regarding sock knitting.

Providing knitting instruction in each class was not easy. I struggled throughout the course to become comfortable with the course timing as it differed from other courses that I was teaching. I stayed late after many classes to provide individual instruction and encouragement for students who wanted it. The amount of class time I provided to students to complete assignments was generous, and many students tended to work on their knitting during this time, when guidance was nearby; they preferred to complete small group assignments after class and through email correspondence. Our Faculty of Education only requires an Honour, Pass, or Fail grade, so grades do not motivate students to complete tasks on time. I had students complete a free-write on this knitting assignment during the course's second-last class, and these personal reflections were used to determine the assignments' success and any changes I should make.

Knitting Instruction

During the first class, I explained the assignment and ended the class with an experiential activity that explored twisting fibre into rope: small groups were to make a thick rope out of paper towels that would be tested for strength. As students twisted fibres, they were to associate their action with as many rope- and yarn-based metaphors as they could brainstorm. It seemed appropriate to start the knitting activity by exploring fibre and the twisting motions involved in yarn production.

In the second class, I focused on their equipment needs and introduced learning to knit. I raised questions to spark a brief discussion concerning the social and environmental impact involved in consumer practices, even something as seemingly insignificant as obtaining knitting materials: students were asked to think about whether they would want to handle wool or synthetic material and whether it was better for the environment to purchase metal needles or wooden needles made in China. At this time, so they could begin practising while they purchased their own supplies, everyone received yarn, two wooden skewers (sanded to a dull smooth point), and a set of directions. Every set of direction came from a different source so each was different: some had illustrations and photographs while others did not, yet all explained the *casting on, knit, and purl* stitches. Students were instructed to learn themselves using only their own set of directions and to mark up their copies with notes concerning all the insufficiencies of their particular set of directions and/or illustrations. After trying to master the stitches for at least a half-hour with just the directions provided to them could they then, if they so desired, try to find a better source for learning. In the following class, a lively discussion ensued concerning what made for the best set of directions and how any images provided aided comprehension or still could be improved. Class time was then provided for students to share what they had learned about the process of learning and to teach one another until everyone could cast on, knit, and purl.

Over the next two weeks students continued to practice knitting and purchase their equipment. They began to create an appropriate-sized pattern by knitting a swatch in order to determine how many stitches needed to be cast on. Along the way, to encourage my students, I shared personal stories of my own frustration having to knit by counting and following row-by-row instructions. I shared stories from Jean Anyon's research and inquired why they thought teachers hesitate to offer their students problem-solving experiences, instead frequently using teaching procedures based upon rote learning. I wore the sweaters my mother had knit me, and I spoke of her diminishing ability to comprehend directions and difficulty doing brain puzzles; I asked if anyone had ever had to deal with seniors, especially in light of Canada's aging demographics and that they might consider working in this area. They were asked to consider the role of lifelong learning in creating healthy individuals of all ages. I shared the pedagogical ideas supporting Waldorf schools teaching kindergarten students to knit and grade five students to knit socks. I asked them to think about how they learn difficult tasks and how any previous learning challenges relate to their experience of knitting socks.

As the students' learning stages became more staggered, I realized the parameters and stress they were encountering. I constantly adapted what I could do in class to help them and always made myself available afterwards for questions. Slowly, I started to worry about the success of this assignment; this concern peaked around the time I provided them with my paper cutout tactics, which had led me to so confidently understand how to turn a heel. The students seemed slow to engage in this activity. They hesitated to answer questions and share any thoughts concerning their understanding of knitting socks. I tried to determine why they seemed reluctant to engage in this problem: did they lack experience using three-dimensional shapes? Were they just tired, stressed, and preoccupied with other assignments? Had they been in classes sitting all day, no longer able to concentrate? They did tape together the paper cutout into a sock form but seemed uninterested in making any connection to the ingenuity early knitters exhibited as they problem solved how to make a heel shape. I would later come to understand that I had introduced this activity too soon: most students were frustrated because they were just seeking more time to repeat the basic knitting procedures rather than moving on to the more complex challenge.

I continued on, trying to accommodate students at various stages of task completion. By manipulating and designing my paper sock pattern, I had solidified in myself the ability to recognize errors and explain things in a variety of ways, and this was a useful skill. I used large needles so it was easier for people to watch my demonstrations. I knitted more socks, leaving them unfinished at various stages of turning a heel so the students could handle these samples to aid their comprehension. I recognized all the problem-solving and critical-thinking skills embedded in this activity, but I wondered if teacher candidates were also able to do so.

The students' class attempts to turn a heel were then disrupted by their two-month departure from campus to complete their teaching practicum. Everyone left with my paper set of directions, and they would now have to teach themselves or find a knitting mentor. Realistically, I knew that most students would not have a teaching schedule that would allow them to complete their first heel. I realized that I might need to lower my expectations for this project and just aim for students to complete one sock with a strong desire to finish the other after graduating. It was during this period that I found the time to finally read some of the books I had been gathering about brain research, and I frequently applied these new ideas to my reflection of what had been happening in this knitting assignment.

When the students returned from their practicum for the final two weeks of classes, I was pleased with the way they focused on completing their socks. Again, I stayed late after classes to provide individual instruction to all who desired it. Over the practicum, a few students had turned to the Internet, friends, mothers, or grandmothers for instructions about completing their sock; a couple of students had mustered through, problem solving with many resources as I had done to try and figure things out. During the last week of classes, students were expected to show me their completed sock(s), or at least what they had been able to accomplish, and this, along with their other assignments, was used to determine an Honours or Pass grade. During the second-last class I had them reflect upon their success and what they had learned through the process of knitting socks by completing a free-write on their experience. During the free-write, I occasionally wrote a question on the board that they could respond to or not. The students' comments[1] during this free-write are the sources of the quotes I use below.

Our final class was spent visiting a sheep farm on a nearby island. On the ferry ride over to the farm, I shared more stories and interesting lore about knitting. I wanted to end as I had begun, by emphasizing connectivity and how one thing can be unravelled into a long yarn of related ideas. The two stories specifically chosen for my few technology students involved knitting while riding on the back of a motorcycle and an incident involving using knitting to de-escalate road rage (Zimmerman, 2005). At the farm, students made many more connections: their questions concerned the meat industry, how waste water is dealt with, and the farmer's ethics concerning predator control. Driving home from the sheep farm, I had two thoughts: I recognized that the whole knitting experience was successful enough that I should try it again, and I should make direct connections to the brain research I had recently read. I had yet to find the time to read the students' free-write reflections, but when I did, they offered me insights on ways I could better make connections between this knitting activity and the way the brain works, ultimately aiming to improve teaching practices to better support learning.

Assignment Evaluation

I entered this knitting project with a strong curiosity but very limited understanding of brain research. I ended with a strong desire to continue learning how to effectively use this research to better my own and student teachers' teaching. My first year of using the sock-knitting assignment had been supported by very informal connections to a very limited understanding of the significant ways both my learning and my teaching could benefit from brain research. I had offered a few of Hannaford's ideas because I had used them briefly before to provide a rationale for climbing activities to outdoor educators. Now I recognized how I could have more effectively used the findings of brain research by examining, in detail, ideas such as what is involved in order to concentrate and what role repetition plays in memory as the students engaged in those aspects of learning through their knitting tasks.

The changes I plan to take in this knitting assignment were based upon my reflections completed after benefiting from reading about how the brain worked. The main change I will make is to combine it with a knitting journal that centres upon students correlating their knitting experience to the findings of brain research. The many journaling activities I now plan to introduce have been arranged into subsections that reflect some of Medina's principles outlined in his book, *Brain Rules* (2008). Because the journaling of the students' experience will take additional time, I have made two changes. I have eliminated another assignment from the course to place a greater emphasis on this one; also, I have requested and received permission to reschedule the course so that classes occur once a week for two terms. The changes I plan to make in this assignment relate to my understanding of how to effectively use and teach brain research in education. My rationale for the changes is explained below; the italic passages and identification numbers represent comments from different students' free-write assignments (GREB, Queens University).

Movement and Concentration

All of the brain research I have read emphasizes the important role of fitness for ensuring proper brain function [Hannaford (2005); Medina (2008); Ratey (2008); and ADEAR (2011)]. As a result of this new awareness, I have increased my own physical activity and am working on ways I can introduce short cardio-based activities in my classes to role model this important principle. My own reflection repeatedly has me aware of feeling more positive and thinking well on days I have exercised. I now seek ways to encourage teacher candidates to become aware of their own patterns that improve and hinder learning. In the final week of the course, I had a lengthy discussion with a student who had realized that she was not capable of teaching in a classroom because she had such a strong need to be physically active. As this was the same student who had shared that knitting had helped her concentrate in her large lecture hall classes, our conversation led to discussing the way schools and work environments could be improved by making accommodation for more physical movement. Knitting is not the kind of physical activity that increases our heart rate, but there might be something very important in keeping our hands a little active in order to aid concentration. Wilson's (1998) book "The Hand…" provides some understanding for the link between hand and brain development, but is limited in the extent it explains the necessity of movement whether in the hand or body for optimal brain functioning.

Hannaford (2005) was the only researcher I read who described the importance of small movements as well as aerobic-based exercise. She emphasized how even small movements can anchor thought: "Many of us have a distinct tendency to think better and more freely while engaged in a repetitive, low-concentration physical task" (p. 109). In describing the way the subtle movements involved in talking can anchor thinking, she also described how chewing gum and knitting can provide similar appropriate movements (without the noise of everyone talking). In my future classes, after outlining the importance of fitness and cardio activity in learning, I plan to share Hannaford's ideas with my students and ask them to note in their knitting journals when they find the subtle movements involved in knitting distract them or aid their concentration.

I also realized that knitting could be used to clarify the link between a person's ability to focus and uninterrupted concentration time. It was during this course that I first experienced many students using screen devices as I taught. As a teacher, I found it distracting but questioned whether I was being unfair because I did not mind students knitting as I lectured. I had explained to students what I consider to be the etiquette of knitting: they should only knit in class when they are so familiar with the skill that they seldom need to look at their hands, and they do not need to read directions, count, or ask a friend for help because this means they are off the task of listening. After reading Carr's (2010) chapter entitled *The Juggler's Brain*, I realized how different technology affects our brain. It can be argued that both knitting needles and screen devices offer low-concentration physical activity; however, today's screen devices are purposely programmed to offer distraction, to pull our thoughts away from tasks we should be focusing upon to instead think about replying to incoming emails, and notice what a flashing image or beep is about. In the future, I will ask students to compare their ability to concentrate on a lecture while knitting to that of having an open laptop in front of them. Their comparisons will be both discussed in class and recorded in their journals in the context of describing what type of activities they will allow their own students in the future to engage in while they are teaching.

Memory

After reading students' descriptions concerning their frustration and their method of learning to knit socks, I realized that what they were expressing was a struggle to engage both short- and long-term memory skills. Many students wrote about their challenges to remember how to knit and purl between the time slots they devoted to knitting.

- *I need clear directions, lots of pictures, and repetition. (6)*
- *Repetition is key in learning a new skill or even a piece of information. (7)*
- *I would try and fail until I got it right. Once I learn a skill on my own, I know how to do it for life; my hands remember long after my brain has forgotten the instructions. (4)*
- *I will try to remember the feeling of frustration of not quite "getting" it and the persistence needed to finish the project. (17)*
- *I hope to finish my one sock and then begin knitting its mate (I hope hope hope I can recall all the first steps to make the second sock). (7)*

After reading Medina's (2008) two principles concerning "remember to repeat" for long-term memory (p. 147) and "repeat to remember" for short-term memory (p. 119), the role of repeating and repetition in memory became clarified. I recognize the way I misinterpreted the students' initial struggle to remember as a disinterest in or reluctance to begin the assignment. To have students engage with the ideas of how memory works in the brain, I will build upon my early activity of having them evaluate the paper directions I gave them to learn the knit and purl stitches. In their journals, the students will extend this initial learning activity by recording directions that they find work as efficient memory aids between knitting time slots. Discussions concerning what make directions and illustrations effective, such as their clarity, conciseness and repeatability will be emphasized. By expecting them to create clear, concise notes to use in supporting their own memory, Medina's short two memory principles can be both evaluated and experienced in their knitting assignment.

Diversity in Learning

As I learned how every brain is wired differently I realize that exploring the way different knitting descriptions cater to different students' learning styles is a useful way to emphasize that teachers should be capable of instructing in various manners. Teacher candidates made similar observations:

- *I noticed that many people in this class were taking different approaches to learn to knit, and I found that really interesting. There is more than one style to teach/learn about any subject, task or idea. (16)*
- *I used multiple methods to try and learn how to knit socks. . . (1)*
- *I found it interesting that no one person learned in the same way. Some were visual, oral, kinesthetic, etc. Knitting was a great experiment to show the different ways of learning. (17)*

As I internalized Medina's rule, "All brains are wired differently" (p. 70), I realized I could plan to have teacher candidates compare the directions they found the most useful with those of their peers and note the differences in their journals. Understanding the role of repetition in building knowledge, being able to prioritize fundamental concepts so clutter does not interfere with retaining key factors, and benefiting from the way understanding is best achieved through various channels with different people are all key concepts for teachers to hold.

Sleep, Nutrition, and Stress Management

The importance of getting adequate sleep, eating well, and reducing chronic stress in one's life are frequently cited in the brain research as critical aspects required for effective brain performance (Medina, 2008; Ratey, 2008). Teachers can be made aware of these principles, but they have little control over how they influence their students' lives. My students commented upon the various levels of stress they engaged in throughout this assignment and described how and why the stress involved in knitting changed:

- *At first I was frustrated, but once I figured it out, I found it very relaxing. I am a very high energy person who never stops thinking and stresses out a lot, so I find knitting to be very relaxing. (12)*
- *When I got into a good flow and knew what I was doing it was relaxing and a stress reliever, yet at other times it was stressful and frustrating. (18)*
- *What can I say about knitting? It was such an interesting experience. I was dreading [knitting] when we were first told about the assignment. I had no*

interest in really learning to knit. However, . . . I found the skill quite relaxing. (16)

- *I feel like I have failed this assignment. However, in ways I have not as I am not giving up. I will persevere until my socks are complete. I just need some more downtime and some more guidance. (10)*

After sharing information on factors that affect brain functioning, such as nutrition, sleep, and stress, I plan for teacher candidates to note in their journal any correlation they observe between such factors and their knitting anxiety levels. I would like them to clearly understand why an activity like knitting can shift between being stressful and relaxing. It is important for teachers to understand how chronic stress influences thinking ability (both positively and negatively) and know about useful strategies for dealing with it in their own and their students' lives. Teacher candidates will be asked to reflect in their journal upon how these ideas will influence the challenges they place on others in their teaching.

Hand-to-Brain Connection

The physicality of knitting and the mental challenges of moving between two- and three-dimensional forms were the original reasons I thought this assignment could be useful at a teacher education level. Below is an example of one student's revelation about learning:

- *I'm still a very kinetic learner. I learn through doing. I need to pick up the materials and somewhat bulldoze my way through it [the task]. Following instructions both irritates and bores me when learning a new skill. (4)*

Next year, I will outline some of the theories pertaining to the role the hand may have played in brain and human development. I aim to provide teacher candidates with more reasons for providing hands-on activities in the assignments they offer to their students. To highlight some of these ideas I will combine Connolly's (2001) (as cited in Hannaford, 2005) and Wilson's (1998) work with the flint knapping skills that Burke and Ornstein (1997) outline that led to the development of language. In one class I will lead an activity where students try to convey a simple task to another person without using words. Through this task they can begin to comprehend how language increases our ability to convey complex skill and leads to logic development. They will then be asked to respond in their journals to this activity and the ideas presented in class that pertain to the importance of conveying hand skill in human brain development.

Vision

One of the reasons few teachers will embark on teaching a craft is because they intuitively know it is best taught in one-on-one relationships because the learner must see the instructor's hand movements. Because providing close-ups are difficult in large classrooms, transmitting craft work that involves students observing fine motor skills is rare in school curricula. New technologies may alleviate that problem; for example, a student in the class told me about some equipment that would enlarge my hand movements onto a real-time screen. Next year, I plan to experiment with using this machine when I give directions so that more students will be able to clearly see what I am doing as I describe my actions. Many students commented upon the importance of the senses, especially vision, in their learning process:

- *I am not a tactile learner but tend to rely on visual and auditory information. . . . I found it so helpful to have my peers walk me through the steps both visually and by talking to me. (1)*
- *I have learned that I need very detailed and illustrated instructions to help me knit socks. I have watched a lot of YouTube videos during this process and found that they helped me a lot with technique. I have always known that I was a visual learner, and this process just solidified that for me. (9)*
- *Knitting has changed my ideas of teaching in a number of ways. First, I learned a lot about how I learn: I am very hands-on and need to be shown how to do something, or have very visual instructions with good descriptions. (16)*

In describing how vision trumps other senses Medina (2008) states: "Educators should know how pictures transfer information" (p. 237). He describes how to effectively use images in presentations to emphasize points. In the future, I plan to demonstrate some of Medina's ideas through PowerPoint slides I design, which will be followed by students creating slides for their journals.

To encourage critical thinking I also will provide students with some of Turkle's (2009) ideas about how the ubiquitous use of PowerPoint presentations in schools has affected youths' ability to think. She discusses how PowerPoint slides are biased towards the use of bullets to convey ideas, which hinders the practice of following long passages of logic as required in reading books. I will ask my students in their journals to comment upon how they can benefit from both Turkle's criticism of and Medina's support for PowerPoint slides in their own teaching. I will then suggest that students question how experiencing the knitting of a sock is like watching a slowly moving video and ask them to discuss to what degree slow movement and time to think are required to develop critical thinking skills.

Brains Desire Learning

The way the human brain has evolved has led us to be natural explorers capable of adapting to change (Medina, 2008). Students' comments reflected this ability as they recognized knitting a sock could be an adventure in learning. Their natural desire to learn as encountered through this activity of knitting socks was initially accompanied by both negative and positive reactions, as expressed below:

- *Learning something brand new is scary and made me feel "young" and "weak." But in the moments that I thought I was getting somewhere, I was proud and empowered. (10)*
- *I look forward to the satisfaction of having my own "home-made" socks and I hope to learn how to knit other things in the future. I loved this assignment!!*
- *. . . and seeing what I was creating was exciting. (16)*
- *I knitted for almost 13 hours, No Joke! . . . In all this time, I only managed to master the heel flap and the turning of the heel on one sock! However, the enjoyment and determination to master certain parts of the sock kept me motivated. It was the fastest 13 hours I have experienced in a long time. (15)*

The sense of intrigue in learning a new skill that can snowball into hours of time passing quickly can be broken down into the concepts brain researchers use to describe how learning and problem solving are "hard wired" into us. In next year's course, I will provide some context for the way this hard wiring works by describing the existence of mirror neurons that are scattered across the brain and why imitation and role modeling is such an effective teaching method. As I present such ideas to my students, I will ask them to reflect upon their own teaching practices. What type of learning activity can be so engaging that it makes time pass quickly? How will understanding the malleability of the brain influence their engagement in lifelong learning? One of the current students already values this engagement; she wrote:

- *I now recognize, however, the importance of learning something new even when you're the "teacher." It's important to challenge ourselves everyday until the day we die. (10)*

To initiate a conversation on these ideas, I may collect written passages about crafts and other activities that describe, in detail, a passion for learning. After sharing these descriptions, I will then ask students how as teachers they will spark an interest in learning in their own students.

Conclusion

Whereas my overall interest in craft work led me to complete my PhD, my specific desire to knit a sock with ease led me to brain research. This case study was about the way I used the activity of knitting socks along with a limited but growing understanding of brain research to improve my own teaching and, hopefully, that of the teacher candidates I work with. By encouraging students to continually reflect on, analyze, evaluate, and write about a sock-knitting experience, I aim to promote their use of recent findings in the area of brain research in their teaching careers. By sharing my own process of discovering the benefits of using brain research in one's work, I plan to have teacher candidates deconstruct the knitting process as they simultaneously knit socks; thereby becoming designers of educational practices that effectively use information pertaining to how the brain works.

Notes

1. I gratefully acknowledge the students and teacher candidates who provided me with permission to use their writing in my quotations.

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The Impact of Visual Frameworks on Teacher Candidates' Professional Reflection

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ABSTRACT

This study examined teacher candidates' reflections about the use of two graphic organizers referenced in their teacher education program. Fourteen themes were identified relating to teacher candidates' instructional focus; awareness of the value of the organizers to improve focus on their students' learning, growth, and independence with instructional tasks; and their focus on professional growth. Data from this study provides information to allow future comparison of teacher candidates' diversity in reflections with their teaching evaluations. Connections with brain development are identified to support the use of complex graphic organizers in professional contexts for teachers.

Objectives

Reflection on professional practice is a commonly expected element of teacher education programs. In our Faculty of Education, teacher candidates learn the skills of lesson planning and lesson delivery in curriculum methods courses. Templates are provided for teacher candidates to show them the elements of lesson planning (Schmoker, 2011). Templates require indications of the pacing of delivery for lessons. However, the linear nature of these templates does not provide the complex understanding of the elements of planning and the recursive nature of effective delivery. To support teacher candidates' understanding of the complexities and recursiveness of this task, researchers developed two graphic organizers that would provide visual support for candidates' understanding. During development these graphic organizers were subjected to the four requirements for conceptual representations as identified by Strauss and Corbin (1990). These graphic organizers will be explained in greater detail in the Perspectives and Theoretical Frameworks section of this paper.

This study was designed to examine teacher candidates' perceptions of the value of these graphic organizers in helping them to understand the various aspects of the planning and lesson delivery decisions they engage in during professional interaction with students. Through reflections, teacher candidates were asked to discuss the value of these graphic organizers to their internalization of concepts about lesson planning and delivery. We examined their reflections to determine the themes that were evident in their discussion and the variety of professional concepts they perceived to be evident in the graphic organizers.

Perspectives and Theoretical Frameworks

Graphic organizers provide visual representations of concepts. They can represent very complex interrelations of ideas. Organizers provide cognitive structures that support learners' ability to relate ideas and support critical thinking and higher levels of cognition (Johnson, 1990; Mayer, 1989). Holley and Dansereau (1984) explain that concepts may be more easily learned if they are presented in a non-linear fashion, as might be supported by a graphic organizer to depict elements of lesson planning and delivery. The use of graphic organizers to support comprehension has its origins in schema theory (Axelrod, 1973; Darch & Carnine, 1986). Research also shows that the use of graphic organizers increases achievement of learning goals by 27 percent (Marzano, Pickering, & Pollock, 2001).

Brain development is closely linked to lifelong capacity in humans. New technology has allowed scientists to examine the brain in ways that is markedly different from approaches used previously. We now know much more about both the circuitry and the neurochemistry of the brain and can make hypotheses about the impact of learning conditions on the growth, maintenance, and health of brain tissue. Current research tells us much about the brain and its capacity for learning. We know that brain development begins pre-natally and extends into adulthood (Webb, Monk, & Nelson, 2001). The brain is specifically designed to incorporate experience into its circuitry and rewires itself to connect new experiences within its developing structure. The research presented in this paper situates new professional experiences in ways designed to create lasting schema that support the developing professional connections neurologically.

Synapses between neurons of the brain and between neurons and the insulating material, called myelin, expand with experiences. Myelin allows the brain impulses to be conducted rapidly among neurons (Craik & Bialystok, 2006; Webb et al., 2001). A richer learning environment, as provided by resources that support conceptual connections in learning new ideas, and more learning opportunities, increase both synapses and myelin (Thomas & Johnson, 2008; Knudsen, 2004). As the brain learns to create more efficient networks and connections, synaptic pruning occurs and decreases the number of neural connections in favour of the most efficient neural connections (Greenough, Black, & Wallace, 1987). The brain is remarkably resilient (Barinaga, 2000; Bruner, 1999). The ability to grow professional concepts through resources designed to help learners make connections can be thought to support the learner's thinking and improve efficiency in recall.

Using this rationale we designed two graphic organizers to help teacher candidates understand the complexities of lesson-planning concepts. The use of these graphic organizers is supported by research into the impact of graphic organizers on the users' ability to relate and retain knowledge and differentiate among the key concepts (in this case the phases of instruction) and related concepts (in this case, aspects of support and assessment that should be available to learners as they engage each phase of instruction) (Hall, Hall, & Saling, 1999).

The first organizer presents a graphic depiction of the phases of instruction. Details of this graphic representation are presented in another paper (Maynes, Julien-Schultz, & Dunn, 2010b) and research related to the application of this model has also been reported in another article (Maynes, Julien-Schultz, & Dunn, 2010a) (see figure 1).

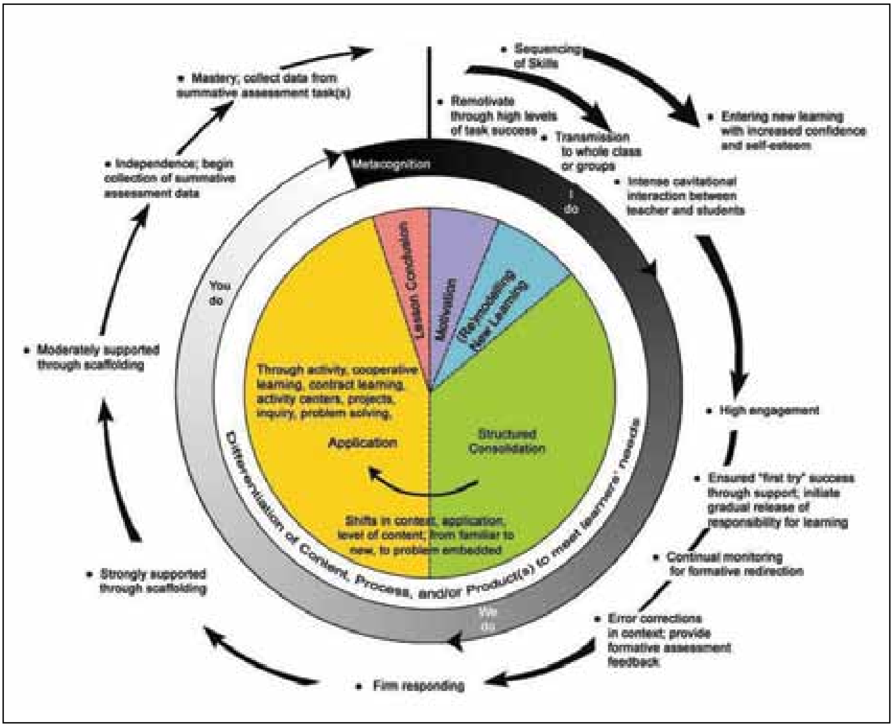

Fig. 1: Graphic representation of teacher actions related to the phases of instruction

As this diagram was used for instructional purposes with teacher candidates it became evident that they needed further support to understand the concepts of the gradual release of responsibility (Fisher & Frey, 2008), differentiated instruction (Tomlinson, 1999), and the different uses of assessment *for*, *as* and *of* learning (Earl, 1995; Earl, 2003). A second graphic organizer was developed to support understanding of these concepts. This organizer used the teacher's voice to represent the professional thinking that the teacher would engage in while planning and delivering phases of a lesson (see figure 2). In this organizer the elements of assessment are the focus.

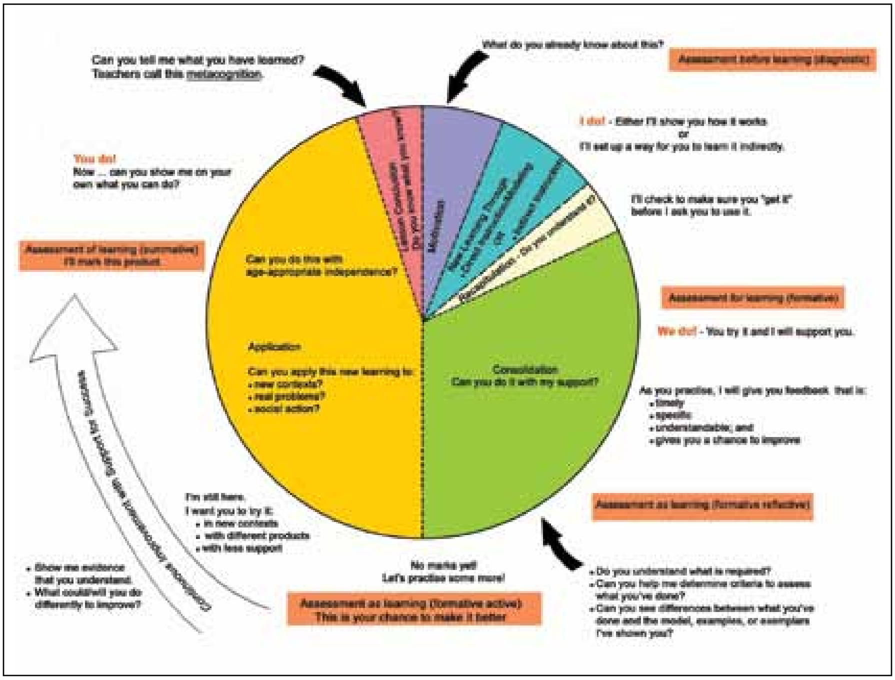

Fig. 2: Understanding the gradual release of responsibility, differentiated instruction, and the different uses of assessment

After using these graphic organizers (figures 1 and 2) with teacher candidates we were interested in examining their perceptions of the value of these organizers to advance their professional thinking.

Schema theory (Axelrod, 1973) holds that a highly accessible schema is checked for understanding before a less accessible schema (i.e., a lesson planning template) is attempted. The graphic organizers are much more accessible than the linear template. Since the visual graphics provide access to the thinking embedded in both direct and indirect modes of instruction, they provide schema that allow teacher candidates to create an available fit to the other information about their professional roles of planning and instruction. If the graphics are known to work for this purpose, teacher candidates should develop more confidence in their ability to apply the general visuals (schema) across contexts. Complex schema also reduces memory requirements because teacher candidates are able to interpret separate bits of information about a current lesson in terms of the parameters of the general schema of either organizer, as consistent with schema theory. The credibility of the figures should be enhanced when the teacher candidates are able to apply them to many lesson instances so they can see the generalizability of the graphic representations.

As in the general theory of schema use, teacher candidates should see the graphics as readily adaptable if they support their interpretation of the needs for a lesson plan or its delivery. For example, a teacher candidate might decide that the consolidation time for a specific skill needs to be greater than the diagrams indicate visually. These graphics readily allow for such adaptation to cases as indicated by the dotted lines between wedges.

Schema theory also holds that a common error in recalling an experience is to recall the part that is compatible with the existing schema and to forget or discard the part that does not fit (Axelrod, 1973). By providing teacher candidates with figures 1 and 2 we theorize that teacher candidates have fewer opportunities to reduce their schema to more simplistic boundaries and must explore the lesson's complex nature more thoroughly.

Finally, each teacher candidate's cognitive style may be reflected in the value he or she sees in the graphic organizers central to this study. In the course context where these visual organizers were used, verbal support was also provided for learning the same skills. By making use of the graphics to support the verbal instruction, the teacher candidates' cognitive style is supported (Mayer & Massa, 2003).

Modes of Inquiry

Teacher candidates complete a number of assignments that provide evidence of their learning in the teacher education program. One of these assignments asked them to reflect on their perception of the value of the two organizers presented in figures 1 and 2. This reflection was subsequent to components of the assignment where teacher candidates were required to develop a lesson plan and reflect on it. These reflections were analyzed by researchers to identify themes that were included (Creswell, 2002).

Forty-three teacher candidates participated in providing access to their reflective writing. Teacher candidates wrote an average of 330 words in their reflection pieces. The median length of reflections was 351 words. A random sample of 20 percent of the teacher candidates' reflective writing was checked by a second researcher to establish inter-rater reliability of the coding process. Both the presence and incidence of each theme was recorded on data charts.

The initial question for this research project was: "What themes will emerge from teacher candidates' reflective writing about the value of two graphic organizer diagrams designed to support their developing conceptions about lesson planning and delivery?" As data was examined, specific questions related to the examination of data and trends revealed by it emerged. These questions included: 1) Which of the emerging themes appeared to be major themes and which appeared to be minor themes? 2) How many of the themes identified by any of the respondents appeared in each respondent's reflections? 3) Did the discrete themes we initially identified cluster into broader themes? and 4) What was the frequency of mention of each theme cluster in teacher candidates' reflective writing?

The first analysis of teacher candidate reflections revealed 14 categories (see figure 3) of themes that they identified as professional ideas attributed to being internalized because of learning the concepts embedded in the graphic organizers (their professional schema). Writing samples were analyzed to determine the percentage of occurrence of each of the fourteen themes. Many themes were evident in the writing of a number of students so it was decided to sort these recurrent themes into the categories of "minor themes" and "major themes." Any theme that occurred in more than 30% of the teacher candidates' reflections was categorized as a major theme. Thirty percent was decided upon as a criterion to be considered a major theme because there was a significant decrease in the incidence of some data categories (themes) below those that appeared in 34% of the writing samples.

We then considered the number of themes mentioned by each candidate. It was evident in some writing samples that several themes were mentioned while other teacher candidates reiterated and developed only a few themes (see figure 5). Once the number of themes was identified researchers decided that it would be valuable to sort themes to determine relationships among themes. By sorting the 14 themes into clusters, three theme clusters were identified (see figure 6). Once theme clusters were evident we reexamined the reflective writing samples and sorted the responses into the three theme clusters to determine the number of reflections related to each cluster.

Examination of the incidence of writings in relation to each theme cluster revealed that one cluster of reflections was more dominant in teacher candidates' writing than the other two clusters. When this was realized we reanalyzed the data to determine the incidence of mention of each theme cluster (see figure 7).

Data Analysis

The 14 themes that emerged from teacher candidates' reflective writing included: understanding planning conceptions, understanding instructional conceptions, time management, support for professional reflection, understanding the gradual release of responsibility, understanding variations of practice for consolidation and application, understanding relationships between successful practice and successful modeling before practice, understanding transitions within phases, framework to support continuous professional growth, knowing when to use various forms of assessment, support to help teachers see opportunities for differentiation, developing students' metacognitive awareness, celebrating evidence of learning and readiness to apply, and understanding that students' success within any phase of instruction influences potential for success in the next phase.

Dominant Themes	Minor Themes
• Understanding Planning Conceptions • Understanding Instructional Conceptions • Time Management • Support for Professional Reflection • Understanding the Gradual Release of Responsibility • Understanding Variations of Practice for Consolidation and Application • Understanding Relationships between Successful Practice and Successful Modeling Before Practice • Understanding Transitions within Phases • Framework to Support Continuous Professional Growth • Knowing When to Use Various Forms of Assessment	• Support to Help Teachers "See" Opportunities for Differentiation • Developing Students' Metacognitive Awareness • Celebrating Evidence of Learning and Readiness to Apply • Understanding that Success within and Phase Influences Potential for Success in the Next Phase

Fig. 3: Themes that emerged from the qualitative analysis of students' assignments

Figure 4 shows the percentage of teacher candidates' reflective writing related to each of the themes. Some categories of reflection showed very high incidence among the teacher candidates' reflective writing. This is consistent with literature related to the use of frameworks for organizing information. Where goals are clear (i.e., to learn how to plan and deliver lessons effectively), learners have been shown to make use of more mature and effective techniques for reaching the goals (Garner, 1990). In this case, teacher candidates indicated that the use of these visual frameworks supported their goal-related access to the complex interconnection of ideas about lesson planning and delivery.

Major Themes	Percentage of Reflective Writing Samples Showing Evidence of this Theme	Minor Themes	Percentage of Reflective Writing Samples Showing Evidence of this Theme
• Understanding Planning Conceptions	93	• Support to Help Teachers "See" Opportunities for Differentiation	13.95
• Understanding Instructional Conceptions	93	• Developing Students' Metacognitive Awareness	9.30
• Time Management	76.74	• Celebrating Evidence of Learning and readiness to Apply	23.25
• Support for Professional Reflection	48.83	• Understanding that Success within any Phase Influences Potential for Success in the Next Phase	16.27
• Understanding the Gradual Release of Responsibility	79		
• Understanding Variations of Practice for Consolidation and Application	37.2		
• Understanding Relationships Between Successful Practice and Successful Modeling Before Practice	44.18		
• Understanding Transitions within Phases	34.81		
• Framework to Support Continuous Professional Improvement	100		
• Knowing when to Use Various Forms of Assessment	39.53		

Fig. 4: Percentage of students who showed evidence of reflections related to the emerging themes in their writing

Teacher candidate responses were also analyzed to determine the typical number of themes mentioned by any candidate. No teacher mentioned all 14 of the themes that emerged from the group. Twenty-nine of the teacher candidates addressed between six and eight themes in their reflective writing (see figure 5). This diversity is indicative of richness of understanding of the complexities represented in the diagrams.

Possible Number of Themes that Could be Mentioned	Number of Teacher Candidates (N=43) who Mentioned this Total Number of Themes in Their Reflection
1	0
2	0
3	3
4	1
5	4
6	12
7	10
8	7
9	2
10	3
11	1
12	0
13	0
14	0

Fig. 5: Number of themes mentioned by teacher candidates

No teacher candidate addressed less than three themes in their reflective writing. Eleven of the 14 themes was the maximum number addressed by any one sample of reflective writing.

We examined connections among the 14 themes that were evident in their writing by asking, "What do certain themes in the writing have in common?" All 14 themes could be catalogued into one of three overall clusters. Teacher candidates' reflective writings were focused on 1) their instruction as a teacher, 2) the learning, growth, and increasing levels of independence of the students they taught, or 3) their professional growth as educators (see figure 6). These clusters represent both knowledge and cognitive processes in a professional context (Brown, 1988; Glaser, 1984; McKeachie, 1988; Rabinowitz, 1988). Each theme cluster includes background conceptions that teacher candidates explained as their understandings related to the conceptual diagrams (knowledge) and the guidance they perceived for professional action during lesson delivery (cognitive processes).

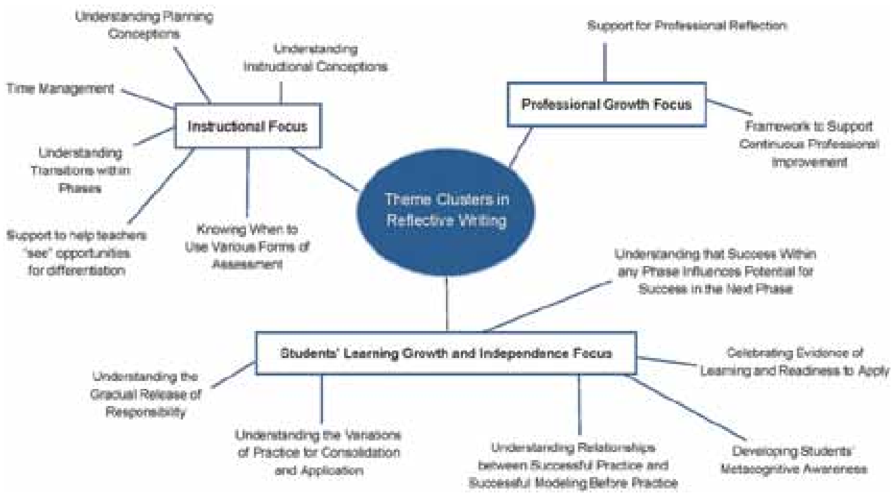

Fig. 6: Theme clusters in the teacher candidates' reflections

We then considered the question, "How often was each of these three theme clusters evident in reflections?" We calculated the frequency of teacher candidates addressing each cluster in their reflective responses (see figure 7).

Instructional Focus Cluster	Professional Growth Focus Cluster	Learning Growth and Independence Focus
Including : Understanding planning conceptions, understanding instructional conceptions, time management, understanding transitions within phases, support to help teachers see opportunities for differentiation, and knowing when to use various forms of assessment	Including: Support for professional reflection, and a framework to support continuous professional improvement	Including: Understanding the gradual release of responsibility, understanding variations of practice for consolidation and application, understanding relationships between successful practice and successful modeling before practice, developing students' metacognitive awareness, celebrating evidence of learning and readiness to apply, and understanding that success within any phase influences potential for success in the next phase
Understanding planning conceptions = 86	Support for professional reflection = 17	Understanding the gradual release of responsibility = 72
Understanding instructional conceptions = 104	Framework to support continuous professional development = 173	Understanding variations of practice for consolidation and application = 18
Time management = 68		Understanding relationships between successful practice and successful modeling before practice = 34
Understanding transitions within phases = 28		Developing students' metacognitive awareness = 4
Support to help teachers see opportunities for differentiation = 7		Celebrating evidence of learning and readiness to apply= 16
Knowing when to use various forms of assessment = 27		Understanding that success in any phase influences potential for success in the next phase= 16

Fig. 7: Theme cluster frequency

By examining the clusters of related themes we were able to determine the concentration of focus within these reflections. This data showed that teacher candidates addressed instructional foci 320 times in the samples (40.7%). Students' learning and growth was mentioned 160 times in the reflections (23.8%). Reflective writing samples focused on the teacher candidates' professional growth 190 times in the writing samples (28.3%). Teacher candidates' reflections focused most frequently on their instructional actions, next most frequently on their professional growth, and least frequently on their students' learning and growing independence with new learning.

Discussion

Lesson planning and delivery are major skills for teachers. In faculties of education teacher candidates often learn these skills by completing templates that are essentially linear. Such templates embed many instructional conceptions that need to be learned by teachers. However, because of the linear nature of templates, they may not allow teacher candidates to consider the intricacies and recursive nature of the decisions they need to make as they plan and deliver lessons (Schmoker, 2011). Such templates may not allow teacher candidates to make connections among the elements of lesson planning and delivery that are known to influence learning (Cochran-Smith, Gleeson, & Mitchell, 2010; Noell & Burns, 2009).

Conceptual diagrams are not constrained by linear representations. They can be used to help teacher candidates visualize the intricacies and relationships of planning and lesson delivery (knowledge) and to internalize a dynamic visual model for the elements they need to address in their planning and delivery roles (processes). Through the use of dynamic visual models for the processes, teacher candidates can learn to be less prescriptive and more intuitive in the way they manage planning and instruction. Visual models that are the focus of this study incorporate fluid knowledge of many interrelated elements of planning. The two models presented in this paper connect concepts related to planning, delivery, differentiated instruction, timing, gradual release of responsibility, assessment and evaluation types and processes, the nature of applications, and student success. By understanding the interconnectedness of these elements teacher candidates were able to reflect upon the graphic representations as they related to their instructional focus, their focus on students' learning and increasing independence, and the teacher candidates' professional growth.

This analysis allowed us to see that the reflective writing is less student focused than we would hope to have seen, with less than one quarter being focused on reflecting about the students' learning outcomes related to their teachers' improved understanding of professional concepts. Instructionally focused reflections were almost twice as likely to be mentioned as either professional growth or students' learning and growth foci. This suggests that teacher candidates still have a fairly mechanical view of the conceptual models rather than seeing the models as supports to help them optimize their focus on student learning.

Teacher candidates' reflective writing showed many benefits of the supplemental use of the two graphic organizers to support their understanding of professional concepts. They are using the two organizers to support both practice and reflection on practice. All teacher candidates said that they could either visualize the graphic organizers as they planned and delivered lessons or they kept the paper copies of each close as they planned. Many said that they used the organizers to support planning in a whole-to-part manner as they approached planning and delivery. They could "see" the whole lesson before they started to write about each part of their plan in the planning template that is prescribed in their program. They saw the graphic organizers as supports for their developing professional schema.

Many teacher candidates spoke about sharing the graphic organizers with others, including their associate teachers, parents who were teachers, or other teacher candidates they met socially or on placements. This sharing activity is indicative of the value they saw in the organizers. The ability to use the organizers to imagine the progress of a lesson seemed to allow most of the teacher candidates to develop a sense of how to manage the allotted lesson time more effectively than they might have without these supports. The brightly coloured wedges and shading in the concentric circles (see figure 1) was seen by teacher candidates as helping them internalize the concept of the gradual release of responsibility as lessons progressed. Teacher candidates seemed to develop a sense of the various forms of assessment and relate these forms of assessment to the many uses of assessment *for*, *as*, and *of* learning.

Major findings of this study include three main ideas. First, this study has provided sound confirmation of the validity of the reflective writing process to have teacher candidates examine their own internalization of professional concepts. Written reflections evidently supported the connection-making process, consistent with brain research. In all reflective responses it was evident that teacher candidates found value in engaging in professional reflection that was supported by having comprehensive conceptual diagrams that organized and related many lesson planning and delivery theories.

Second, teacher candidates expressed unanimous appreciation of the conceptual diagrams in their reflective responses. They identified that the diagrams helped them connect many concepts related to their professional roles and to relate the ideas in the diagrams to their professional conversations. They expressed the value of the diagrams as summative models that pulled ideas together for them.

Third, it is evident that even with the support of comprehensive conceptual diagrams most teacher candidates have not developed a perspective on their professional role that allows them to shift their thinking from focusing on their teaching duties toward focusing on students' learning, as shown in the incidence of writing about the learning growth and independence cluster (see figure 6). While this shift was evident in 9% of reflective responses, we consider this to be a remarkably low return in understanding given the purpose of the graphic organizers. Although this concept was mentioned 160 times in the 43 writing samples, it was the weakest of the three reflective writing theme clusters that were identified in teacher candidates' writing.

It may be that we, as researchers, see the three clusters of reflections in a hierarchical manner. If we consider the instructional focus to be the focus most likely to appear immediately in teachers' professional development, and their focus on professional growth to be the next most likely as they end their professional preparation program and begin searching for a job, we gain some perspective on why their focus on students' growth was the weakest of the three areas of reflection in their writing. This sequence may simply reflect the realities of their stage of development within the profession. From this perspective, it is perhaps rewarding to see as much focus on students' learning as was evident in the reflective writing. This may indicate that there is a sequence in the thinking of teacher candidates that leads them to focus first on what they do as teachers, next on what they can do to improve, and finally on what they can do to support their students' learning more effectively. If this is a predictable sequence of foci as teacher candidates mature as professionals, it will have implications for professional preparation programs. If we can make this sequence of foci visible to teacher candidates and to their professors, we can provide more specific attention to each area of development and pursue development of focus on students' learning more intentionally.

Further parallel study is underway to examine the professional characteristics and dispositions of teachers who make this shift in their thinking (Maynes & Hatt, 2011).

The focus on instructional actions rather than on student learning in professional reflections may partially be accounted for by the theory of settings (Garner, 1990). This theory suggests that learning strategies may vary when the context of use and need vary. Since the teacher candidates were making use of these visual frameworks in the context of assignment and testing reflections, rather than in actual preparation for classroom instruction, their focus within the reflections may have been influenced by the context of strategy use. Much more focus on student learning in actual reflections might have been evident if teacher candidates had actually taught the lesson and were reflecting on its success. If the nature of the strategic reflective activity varies with context we might expect teacher candidates to be less vigilant about the nature of their reflections when their professional tasks result in more duties and responsibilities and less time to complete them. Differential strategy use by setting is well documented in research literature (Garner, 1990). We have no reason to suspect that general findings about strategy use would not also apply to teacher candidates' use of the visual organizers to support their planning and lesson delivery. Evaluation on one's knowledge is essentially a metacognitive activity. There is no doubt that teacher candidates found the visual models to be valuable in helping them to understand the concepts that underlay the complex processes of lesson planning and delivery. The diversity of key ideas they attribute to their understanding of these models is evident from this study. Because these visual models support access to complex elements that interrelate one's knowledge of learning to plan and deliver lessons, we can expect that these models will continue to be valued as professional tools.

This study informs our practice as teacher educators. Awareness of the key messages that teacher candidates have taken away from their personal use of these graphic models may also help us attend to highlighting embedded messages more effectively. In our future use of these organizers we can address Garner's theory of settings (1990) more directly to make teacher candidates aware that some aspects of these organizers may have more relevance at different stages in their development as professionals. We can emphasize the value of these organizers as frameworks to support students' learning.

Future research will seek to identify possible alignment between the diversity in teacher candidates' reflective writing about planning and lesson delivery concepts and evaluations of their teaching skills.

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The Impact of Emotions on Divergent Thinking Processes: A Consideration for Inquiry-Oriented Teachers[1]

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ABSTRACT

Innovation is a cornerstone of the success of our global society and it is required to generate solutions to today's challenges. Students will benefit from classrooms that encourage creative thought and innovative self-directed projects. Inquiry is an instructional approach that fosters creativity and divergent thinking. This paper elaborates on one aspect of the creative process—the impact of emotions on divergent thinking. Theory and some existing research are reviewed and a plan for a neuro-cognitive study using electroencephalography is delineated. Current and previous research is taken into account when reflecting on suggestions for fostering learning environments conducive to creativity and building interdisciplinary collaboration.

Historical innovations that are integral to today's daily routines include the magnetic strip on our bank and credit cards, introduced publicly in the 1970s; and the innovation of the mass production of cars in the late 1800s. The leaders of these innovations could not have predicted the impact they have made on today's global economy, physical landscape, and environment. We do not know where our most recent innovations are taking us, but there is little doubt that they are changing our paths and allowing for a future that would otherwise not be possible.

How do we nurture the skills necessary for our students to become tomorrow's leaders of innovation? Students will benefit from teachers who understand where good ideas come from and how individuals engage in the creative process. This paper discusses some of the ways this area of inquiry is being tackled, particularly, the work of the authors to better understand one intrapersonal aspect of the creative process—testing the impacts of emotions on divergent thinking processes in an electroencephalography experiment.

Innovation and Creativity: An Educational Goal for the 21st Century

Every person benefits greatly from innovative people and groups. YouTube's (http://www.youtube.com/t/press_timeline) 2005 launch and Wikileaks' (http://wikileaks.org/) official launch in 2007 revolutionized media, how we engage with it, and our level of comfort with sharing and consuming information that has previously been deemed private for individuals, corporations, and governments. A landmark scientific discovery was made in 2010 with the first synthetic cell invented by J. Craig Venter and team: http://www.sciencemag.org/content/329/5987/52.abstract, http://www.guardian.co.uk/science/video/2010/jun/04/craig-venter-synthetic-genomics?INTCMP=ILCNETTXT3486. This innovation is expected to lead to new vaccinations and is imagined to lead to new avenues for tackling disease and improving health. BIXI, a term coined from the combination of bicycle and taxi, is a transportation system implemented successfully in Canada in 2009. BIXI has provided a novel solution for urbanites seeking affordable, ecologically friendly transportation (https://montreal.bixi.com/) by allowing people to make one-way trips with city-owned bikes. These are only three specific examples of how today's innovations can impact any and every aspect of today's society.

Innovation and the creative process are topics of interest across a wide array of professional groups. The journalist, Steven Johnson (2010), wrote a book and gave a TED Talk *Where Good Ideas Come From* wherein he discussed sociological contexts in which good ideas flourish (http://www.ted.com/talks/steven_johnson_where_good_ideas_come_from.html). The question "Where do good ideas come from?" has been asked by many academics and teachers alike. The elusive "Eureka!" moment is not as romantic and spontaneous as it is generally understood to be. Johnson explained the slow process of Darwin's theoretical developments and the role of the Enlightenment Era salons and English coffee houses (see Fig. 1) in exchanging ideas

Fig. 1: Poet's artwork

and making unpredictable connections that lead to innovations—eventually. Johnson referred to this process as the slow hunch.

How do we teach students to generate their own slow hunches? How do we make our classrooms look more like 18th century coffee houses (with a fuller representation of cultures and sexes)? How long does a classroom-based slow hunch take? Johnson (2010) did not speak directly to educators, but there is much to be gleaned from examples of creative best practices when planning and enacting inquiry-learning contexts that hope to achieve such high-level learning outcomes.

Understanding Creativity in the Inquiry Classroom and Neurocognitive Laboratory

Developing the individual ability to create novel ideas of importance to society is an educational goal of great importance. Such creativity can be fostered in any subject area, and at any age. Shore, Birlean, Walker, Ritchie, LaBanca, and Aulls (2009) defined inquiry-literacy and outlined vignettes of what inquiry can look like in science, social studies, and mathematics. Inquiry is a multifaceted, student-centered approach to learning that focuses on creating opportunities for students to engage in interest-driven active learning. In inquiry learning environments, students' interests direct learning activities. Each student has the opportunity to create his or her own research question or project to pursue. Taking a more active role requires students to take some responsibility for their learning and results in a sense of ownership over the knowledge constructed in the class. Such classes are nurturing contexts for creativity because there are many open-ended problem spaces. When a specific response is not sought by close-ended activities or evaluations, students are able to make connections and contributions to the class not necessarily anticipated by the teacher. Problem finding, one of the more creative tasks in the inquiry process, is when a student comes up with a novel question (or novel means for answering a previously asked question) that has relevance to an outside audience (Hayes, 1989; LaBanca, 2008; Ritchie, 2009).

Necessary to all problem finding and other creative acts that lead to innovation is the ability to think divergently—outside the box. To see a novel angle on an old problem, or to generate a question that has not previously been asked. Divergent thinking ranges from creating artificial cells that will change the face of medicine to the everyday ingenuity of finding ways to stick to a budget, drawing, or creating a new recipe for dinner. Divergent thinking is a cognitive process necessary for large- and small-scale creativity that can be engaged in everyday. For benefits of everyday creativity see: http://www.psychologytoday.com/articles/200910/everyday-creativity.

The skill of being able to generate novel and useful ideas can be informed by emerging work in the cognitive and neurological sciences. Breaking down the problem-finding process in applied studies has been the work of LaBanca (2008) and Ritchie (2009). LaBanca (2008) studied high school students who presented their self-directed projects at a statewide science fair and at the 2007 International Science and Engineering Fair in a multi-case qualitative study. Through interviews, document analyses, and surveys, LaBanca explored the process and outcomes of problem finding from the perspectives of students, teachers, mentors, and fair directors. Through retrospective accounts, the problem-finding process was reported as being idiosyncratic, nonlinear, and flexible, similar to the findings of Getzels and Csikszentmihalyi's (1976, see p. 27 of introduction) study of art students. This result indicated to LaBanca that this truly student-directed form of inquiry might open doors to creative and analytical thought that might not be present in other forms of instruction. Ritchie (2009) looked closely at similar students engaging in the same open-ended inquiry process to document some of the details of students' experiences with this creative and flexible process as it unfolded through the school year. Ritchie found that students who engaged in problem finding had more intense emotional experiences during class time compared to students in inquiry classes not required to problem find, from the full range of positive to negative as assessed by the Positive and Negative Affect Questionnaire (Watson & Clark, 1994). The heightened emotions that participants reported were interpreted to be due to the personal investment required to engage creatively, to put themselves into their schoolwork in a way not typically required of them. Results from these naturalistic studies inspired a leap from classroom to laboratory to shed more (and different) light on how emotions impact divergent thinking. Divergent thinking is our cognitive process of interest because it was evident during Ritchie's classroom observations that thinking divergently was key to students coming up with novel research questions. It was clear from classroom observations and student and teacher interviews that divergent thinking was a common and important component of their creative processes.

Advances in the neurosciences are not finding one (or even three or four) specific brain regions associated with creative thought or insight experiences. Dietrich and Kanso (2010) published a review of 63 articles (reporting 72 experiments) exploring the neural mechanisms of insight and creativity. Neuroimaging results only showed diffuse prefrontal activation and EEG studies had inconsistent results across studies. An inconclusive picture was also drawn based on artistic creativity studies. Given that creative and insightful acts comprise many specific cognitive processes and brain regions, it is not surprising that results were varied. Lack of evidence certainly does not call into question the existence or importance of studying the creative process. Instead, cognitive researchers need to identify component processes critical to creativity that can be operationalized, isolated, and observed within the necessary constraints of experimental cognitive neuroscience. The moment of insight, the stroke of genius that many creative people crave, might be an identification of the moment when all of the necessary and slowly evolving pieces come together. An innovation is the outcome of the dynamic relationships between the social settings, the time frame required for its development, interpersonal dynamics between collaborators, and the intrapersonal dynamics within each collaborator. People are social and cultural beings who have constant interaction between their interpersonal and intrapersonal processes (Vygotsky, 1978). Cognitive neuroscience is well equipped to inform some of the intrapersonal components of the creative process.

The Impact of Emotion on Divergent Thinking Processes

Barbara Fredrickson's (1998, 2004) *Broaden and Build Theory of Positive Emotions* explains that positive emotions have an evolutionary function, which is to broaden people's perspectives. Broadening encourages people to pursue a wider range of thoughts and actions than is typical for an individual or social context. Activities that evoke positive emotions, such as interest, joy, and excitement should broaden people's thought-action repertoires. "Experiences of certain positive emotions prompt individuals to discard time-tested or routine behavioral scripts and to pursue novel, creative, and often unscripted paths of thought and action" (Fredrickson, 1998, p. 304). Negative emotions, on the other hand, are theorized to be associated with the narrowing of thought-action repertoires. This proposition stems from an evolutionary perspective; quick, concise, and convergent thinking is functional in threatening situations.

Interest is an emotion that occurs in social contexts that are safe and offer a sense of novelty, possibility, or mystery (Izard, 1977). Social contexts conducive to feeling interested are also perceived as important and demanding of attention and effort. An interested mind is broadened in that it evokes a mindset of openness to new ideas and experiences. The thought-action tendency resultant from interest is exploration with the goal of increasing knowledge and experience. Openness and willingness to take action to explore builds on existing knowledge structures (Fredrickson, 1998). Contentment is a family of emotions that includes tranquility and serenity, and which is most often experienced in safe social contexts that have a high degree of certainty. When content, people are able to savor current life situations and accomplishments. This is a time for holistic reflection and relation of self to larger social cultural contexts. The outcome of this thought-action repertoire is a building of cognitive resources; reflection leads to strengthened knowledge structures and perspective about who you are and what you think in relation to others. Play and exploration are likely when experiencing positive emotions and the associated thought-action repertoires promote discovery of novel ideas and actions. There is empirical evidence to support the theory that momentary emotional experiences change cognitive perspective; people in positive moods tend to be global information processors, whereas people who are sad tend to narrow their attention and focus on the specifics of a situation (Gasper, 2004). No study has yet to use ERP methods for tasks that require participants to engage in divergent thinking while induced into specific positive or negative emotion states.

What is the advantage of understanding emotions' influences on divergent thinking? How does the above theory apply to teaching and learning? Learning activities that minimize negative emotions are hypothesized to also minimize narrowed focus and convergent ways of thinking. Activities that evoke positive emotions, such as interest, joy, and excitement, are hypothesized to broaden students' thought-action repertoires and lead to student-directed creative endeavors. It is not our goal to create a global dichotomy between the benefits of positive emotion states and the disadvantages of negative emotions. Inquiry students reported significantly more negative emotions (Ritchie, 2009) than their peers in teacher-directed classrooms. Both positive and negative emotions might be inevitable, and can have their benefits. Having an eye for detail and a narrow focus might be beneficial for some specific tasks involved in the research process, but innovation cannot be achieved without the divergent thinking hypothesized to be more likely during positive than negative emotion states.

A Neurocognitive Research Study in the Making

We are in the beginning stages of collecting data for a study that we describe briefly here in order to exemplify how we can test the above directional hypotheses using neurocognitive methods. It would be premature to assume that our hypotheses will be confirmed. The goal of this paper is to invite a multidisciplinary conversation about the role of cognitive neuroscience in building evidence to support creativity in best inquiry practices.

Barbara Fredrickson's theory of positive emotions proposes that positive emotion states lead to broadened perspective taking and cognitive flexibility, and inversely, that negative emotions have narrowing effects on these processes. Do people perform differently in tasks that require divergent thinking when *happy* versus *serene* versus *sad* versus *disgusted*? We plan to test this theory by inducing participants into one of four emotion states (happy, serene, sad, or disgust) and having them complete divergent thinking tasks that assess their cognitive flexibility in an event-related potential (ERP) experiment using electroencephalography (EEG). These four emotion states were selected because they are distinct from each other and have been used in previous studies requiring emotion induction in laboratory settings. There are many nuanced positive and negative emotions that might be more applicable to a classroom setting (e.g., interest, anxiety, frustration), but are more difficult to induce in an experimental context. Our first goal is to look for evidence of differences between positive and negative emotion states in general. If our hypotheses are confirmed, future work could begin to explore a wider range of emotional experiences.

Emotions will be induced by watching emotionally salient videos during the laboratory task. After participating in the ERP experiment with the videos, participants will be asked to complete a self-report assessment of a full range of emotional experiences in order to confirm how they were feeling. Emotions extraneous to the assigned conditions will be used as a covariate in the analysis of results. Participants who did not adequately report emotional experiences in line with the group to which they were randomly assigned will be removed from analysis and their performance will be reported separately.

Electroencephalography (EEG) is a non-invasive measure of electrical brain activity by nodes attached to a cap that is worn on the head. An EEG is a recording of electrical signals from the brain made by placing electrodes (small metal discs) on the scalp. The electrodes are generally in a net (like a hair net) that is placed on the participant's head. These electrodes pick up electrical signals that are naturally produced by the brain, and send them to a computer where they can be stored and later analyzed. EEGs allow us to follow electrical impulses across the surface of the brain and observe changes over split seconds of time.

The event-related potential technique (ERP) collects electrophysiological data through EEG. ERPs are designated potentials that have reliably displayed relationships between timing of a specific positive or negative voltage and a definable event. ERPs measure how long it takes the brain to process stimuli or to perform specific cognitive processes during researcher-constructed and highly controlled tasks in experiments. The timing measured for specific electrophysiological responses are within milliseconds of the stimuli being presented to the participant on a computer screen. Electrophysiological recordings are relatively variable between repeated events. Results that are interpreted in studies are an average of voltages measured over multiple trials (often hundreds). Over decades of research, many responses have been generally agreed to be associated with specific processes. For example, the N100 wave (a voltage detected with a latency of approximately 80-140 milliseconds after stimulus presentation) is sensitive to attention (Parasuraman, 1980; Luck, 2005). This means there is a dip in voltage at approximately 100 milliseconds after presentation of a stimulus if a participant is paying attention. There is something appealing about the notion of actually being able to document whether or not a student is paying attention! The N400 wave has been associated with identification of incongruency during cognitive tasks. For instance, if one word follows another that is highly related ("coffee," then "cream"), there will be no identifiable dip in electrophysiological activity at 400 milliseconds after presentation of the second word. If a word incongruent with the first word is presented ("coffee," then "socks"), there will be a negative voltage detected through EEG at approximately 400 milliseconds. This allows us a way to measure, aside from just asking the participant, if he or she perceives a relationship (or lack of relationship) between two words.

Divergent thinking is being able to see relationships in unconventional places. Coffee and socks are not so incongruent if you are thinking about ways to warm up on a cold day. Thinking about new uses for common tools is an example of a divergent thinking exercise. How many uses can you think of for a fork? If you only think about eating, you are not thinking divergently. What about combing your hair, using it as a paintbrush to create texture in a painting, cleaning a gritty surface, re-shaping it to make jewelry, bending some prongs to make a place-card holder at the dinner table, or hanging many together to make a wind chime? Divergent thinking is a cognitive process that has great implications for education, particularly problem finding in inquiry contexts (Shore, Aulls, & Delcourt, 2008). Divergent thinking is a fundamental skill for flexible thinking and creativity in brainstorming and ill-defined problem-solving tasks (Hayes, 1989; Newell, Shaw, & Simon, 1964). A task that assesses divergent thinking that can be completed in an ERP experiment involves presentation of hundreds of word pairs. Participants are asked to rate on a visual-analog scale that is presented on a computer screen the extent to which two words are related, from "not at all related" to "very related." When a participant sees incongruence between the meanings of two words, an N400 is expected to be detectable.

If *happiness* evokes a readiness for creativity and *serenity* evokes a reflective mindset to savor previous experiences, then it is hypothesized that participants induced to feel *happy* will have less activation of the N400 for conventionally incongruent words (both groups will have the same lack of N400 for extremely congruent word pairs). Because of the actual narrowing effects of feeling sad or disgusted, participants induced to feel sad or disgusted are hypothesized to have greater activation of the N400 for conventionally incongruent words (and the same lack of N400 for extremely congruent word pairs) in comparison to participants who feel happy or serene.

This study design has required a little methodological innovation. With the goal of making participants feel authentic and sustained emotional experiences (while randomly assigned to be happy, sad, disgusted, or serene), the team was required to create emotion-induction techniques that would be effective in the EEG laboratory context. Further, divergent thinking has previously been assessed using tasks where participants need to make dichotomous decisions and classify word pairs as congruent or incongruent. There are no shades of grey allowed in the decision making required in traditional congruency tasks. We expect that participants in positive moods will see the shades of grey—it is hypothesized they will see that some words are more or less related to other words. Using a visual analog scale to make judgments of congruency in an ERP experiment is a new and more ecologically valid method for assessing divergent thinking.

Classroom Involvement and Implications

In an ideal inquiry classroom, the responsibility for learning is shared between the teacher and students. Students take on more diverse roles, some of which are traditionally the domain of the teacher, and direct what and how they will learn with guidance from their teacher and peers. Ultimately, the goal of inquiry is for students to engage in investigations guided by personal interests. Integrating curricula and students' interests in a meaningful way makes learning a far more personal process, in comparison to studying the content of assigned chapters or practicing word problems. It is logical that greater personal investment would result in heightened emotional experiences. Potential emotional experiences include vulnerability and anxiety around sharing personal thoughts with teachers and peers, confidence to take risks and brainstorm new ideas, excitement when exploring new areas, pride of outcomes. The potential emotional experiences are vast and require further investigation to delineate which are most common in inquiry settings. We recommend that educators be aware of the heightened emotional experiences of students in these open-ended learning environments. Students might need some extra encouragement to open up, they might need a pep talk when their idea does not work, or when they realize they should change their topic for logistical reasons. A teacher's ability to welcome unexpected responses and to tolerate the unproductive phases a student might go through is critical to the success of the truly student-directed inquiry classroom. This is not to say that the teacher needs to attend to all emotional reactions, or even that the student will explicitly share these experiences with his or her teacher. The argument here is that when learning is self-directed, it becomes personal and when something becomes personal, the emotional valence of the learning process increases. An awareness of this aspect of the student experience can help teachers better understand their learners, which will undoubtedly facilitate one's ability to support them through the inquiry process.

Going back to Johnson's explanation of innovation coming from slow hunches, how long does a classroom-based slow hunch take? Students need to be able to have both focused and unproductive phases and to be able to work at their own pace—every student cannot come up with their good idea in one class or even in one week. High school students in an applied science research class took from two weeks to three months to generate a novel research question of personal interest (Ritchie, 2009). This timing was counting from September. Many of the students who participated began conversations with their teacher in the summer months, or even the school year before their Applied Science Research class. It takes time to identify interests, learn more about them, shift focus, look for problem spaces, and finally commit to (and complete) a novel and innovative project. For a general discussion of teaching and learning strategies that promote creative problem finding, see LaBanca and Ritchie (2011).

Inquiry classrooms that are flexible and truly student-directed regarding how and when a project unfolds will be breeding grounds for creativity. This flexibility can involve loud conversations among students and teachers, much like 18th century coffeehouses. It will involve students at varying stages of their projects in the same room. Some will have moments of focus and confidence on the same day that others are discouraged or intimidated. Having awareness of the emotional experiences of students will help teachers be able to give students the guidance and support they need to think creatively. One goal of the above study and the team's larger program of research is to describe in detail how emotions relevant to classrooms impact cognitive processes that are the building blocks of creative thought.

Conclusion

It is necessary to maintain collaborative relationships between the researchers involved in the aforementioned experiment and teachers who share an interest in this work. These teachers, as recommended by Szücs and Goswami (2007), play a critical role by sharing their extensive practical experience to inform research questions and future directions for research. A multiple-methods approach to creating programs of research is called for. Following the tradition of Donald Hebb (1949), we strongly believe that multiple areas of Education and Psychology should collaborate to lead to generalizable theoretical insight. There is a current movement to bridge the divide between research in education and our understanding of the neurocognitive processes involved in learning and emotion (Immordino-Yang, 2008; Szücs & Goswami, 2007). Applying the important insights gained from neuroimaging research to actual educational settings is a lofty goal whose realization will take some years yet (Nature Neuroscience Editorial, 2006). However, the critical first step in this endeavor is interdisciplinary collaboration in which expertise from both areas is combined.

> If we want to integrate neuroscience and education, sending information between education and neuroscience across bridges is not the answer. Simply taking results and interpretations of (cognitive) neuroscience, relating them to an educational context, and then drawing conclusions for education does not integrate the two disciplines. What we really need is a new

> colony of interdisciplinary researchers trained both in cognitive neuroscience and in education. (Szücs & Goswami, 2007, p. 117)

It is not always feasible to be retrained or to become expert in all areas relevant to our personal interests. It is in new research groups, new social networks (in a coffee shop, university, school, or a Google + group) that areas of expertise can merge and inform each other, forming ideas and generating theoretical insights and pedagogical innovations not otherwise possible. We can build collaborations between research and practice that can be mutually informative. Insights from inquiry teachers have already informed the described study and they are keen to learn of the results. Classroom-based research by this team is being conducted in tandem with the laboratory-based research. If both areas of research triangulate to support the theoretically driven hypotheses, then there would be substantial evidence in support of using this framework to better understand the intrapersonal emotional and cognitive components of students' learning processes. We hope that this discussion serves as an impetus for readers (educators and researchers across disciplines) to contact us and engage in conversations about the evolution of this program of research.

Notes

1. Parts of this paper were taken from Ritchie's Doctoral Dissertation: Ritchie, K. C. (2009). *The process of problem-finding in inquiry education: A focus on students' experiences*. Unpublished doctoral dissertation in Educational Psychology, McGill University, Montreal, Quebec.

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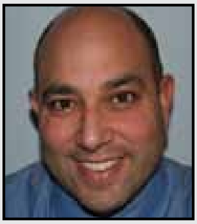

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LINK TO:

http://neuroimaging.psychology.dal.ca

http://problemfinding.labanca.net

Theorizing an Integration of Reading and Mathematics: Solving Mathematical Word Problems in the Elementary Grades

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ABSTRACT

This article theorizes three major cognitive constructs that are operationally defined by shared similarities of processing information in reading and mathematics. Specifically, the paper (1) proposes and details the refinement and evaluation of components of a conceptual model for reading to solve mathematical word problems for elementary students, and (2) develops and refines the theoretical constructs of the model. Our assumptions lay out the interrelationships of reading and mathematics word problems by focusing on the cognitive components of Recognizing Higher Level Patterns of Text Organization (R), Generating Patterns (G), and Attaining a Goal (A). These assumptions are to refine and construct the RGA cognitive components that could theoretically enhance elementary students' reading and solution of mathematical word problem-solving abilities.

> WASHINGTON (Oct. 14, 2009) — *There has been no significant change in the performance of the nation's 4th-graders in mathematics from 2007 to 2009, a contrast to the progress seen from 1990 to 2007 at that grade level and subject, according to the 2009 National Assessment Governing Board (2009) in mathematics.*

Historically, several educational interventions have been suggested to improve mathematics achievement in the United States without a significant degree of robust success. Among the first that received broad attention, was the move to conceptual development using manipulatives in the New Math era (Driscoll, 1983; Fennema, 1972; Sowell, 1989; Suydam, 1986; Suydam & Higgins, 1976). However, this innovation was questioned when in international student comparisons the U.S. performance did not improve (Baroody, 1989; cf. Clements & McMillen, 1996). A gradual movement emerged in the field that resulted in a greater emphasis being placed on testing mathematics through contextualized problems referred to as word problems. The shift in emphases to word problems resulted in key word strategies gaining favor (Fuson, Carroll, & Landis, 1996; Harris & Pressley, 1991; Pressley, Levin, & Delaney 1982); however the efficacy of this strategy failed to provide any dramatic change in student performance or improvement in the United States' international mathematics ranking (Mullis, Martin, & Foy, 2008; Organisation for Economic Co-operation and Development [OECD], 2006).

Recently, Slavin and Lake (2008) comprehensively examined various types of current mathematics programs available by placing them on a common scale using best-evidence synthesis. They computed effect sizes and also provided a description of the context, design, and findings of each experimental study. The evidence from their review of 86 studies supported several conclusions: (1) there were few high quality studies, (2) more randomized program evaluations used over longer time periods were needed, (3) textbooks and mathematics curricula used for instruction did not matter much and little evidence of strong effects were found, and (4) studies of Computer Assisted Instruction contained modest effect sizes and some showed positive effects for computation. The most promising conclusion to assist with theoretical reformation from Slavin and Lake was the effect for programs that targeted teachers' instructional behaviors (ES = + 0.33) rather than the content of the programs. They noted, "Supplementing classroom instruction with well-targeted supplementary instruction is another strategy with strong evidence of effectiveness" (p. 481).

The use of computer software programs in increasing students' proficiency in reading and mathematics skills has been growing. However, the results have not been promising. Campuzano, Dynarski, Agodini, and Rall (2009) examined the effects of 10 reading and mathematics software products on student achievement. Their study tested the effectiveness of each software product by comparing the standardized test scores of students in classrooms using the products to those of students in similar classrooms not using the products. They reported one statistically significant effect for the six reading programs examined (*LeapTrack®*, 4th grade). The estimated effect size was 0.09, which they noted as the equivalent of moving a student from the 50th to the 54th percentile in reading achievement. None of the four math programs in the study demonstrated significant effects on students' achievement. These results, coupled with those presented above, give rise to the need to explore alternative structures and constructs for helping students to develop mathematics proficiency with word problems. In conjunction with the results emanating from Slavin and Lake (2008), researchers need to strive to change how teachers teach in order to produce the most promising outcomes for students' increased achievement. Thus we theorize a potential set of cognitive components in mathematics that focus on the reading demands of word-problem solutions—contextualized reading, vocabulary development, problem-solving structure comprehension, and concept development (Capraro & Jofrion, 2006; Capraro & Capraro, 2006; Rupley, 2006). Cognitive growth can be developed in and through both reading and mathematics. Mathematics educators have begun to recognize the importance and contribution of reading comprehension skills to students' mathematical success (Adams, 2003; Barton, Heidema, & Jordan 2002).

Perspectives on Previous Theories

Several models have been suggested that account for the nexus of reading and mathematics. The National Council of Teachers of Mathematics (NCTM) proposed that students read to learn mathematics (NCTM, 2000). However, this proposal lacked the details to disaggregate the reading factors that specifically contribute to mathematical learning. In general, some factors have been identified from mathematics and reading research. There remains a need for research on the development of fully articulated mathematical instruction programs that (a) use what research has shown to be effective and (b) improve our future knowledge base—research that enables investigators to explore intervention efficacy in natural school settings (Cheung & Slavin, 2005; Slavin & Lake, 2008). The most promising models for using reading to improve mathematics strategies were expressed as including: a) application of reading for meaning, (b) vocabulary development, (c) chunking, (d) language usage, (e) inference, (f) reflection, (g) didactics in multiple meanings, and (h) using problems closely linked to students' real-world experiences (Powell, Fuchs, Fuchs, Cirino, & Fletcher, 2009).

Overview

Two main objectives are outlined here that identify and assemble the shared constructs of reading and mathematics for the conceptual developmental of a theory of reading and mathematics for solving word problems. A feature of mathematical performance that has not been extensively studied is elementary students' solution of word problems, which is perhaps due to the fact that, " . . . to solve a word problem, students must use text to identify missing information, construct a number sentence, and set up a calculation problem for finding the missing information" (Powell et al., 2009, p. 2). We offer our assumptions about the shared constructs followed by sections theorizing the (1) refinement and evaluation components of Recognizing, Generating, and Attaining (RGA) that would have application to reading and the solution of word problems in elementary students; and (2) develop and refine the essential applied constructs of the theory. Our assumptions lay out the theoretical and research-based interrelationships of reading mathematics word problems by exploring and substantiating the cognitive components presented in Table 1: (1) **R**ecognizing Higher Level Patterns of Text Organization, (2) **G**enerating Patterns, and (3) **A**ttaining a Goal—**RGA Theory**. These assumptions are to refine and construct the RGA cognitive components that could lead to an application that would increase elementary students' mathematical word problem-solving abilities.

Table 1

Three Broad Components of Cognition (Adapted from Rose, 2005) Reading Strategies Form the Constructs of Mathematics Strategies

Reading Strategies	Mathematics Strategies
RECOGNIZING HIGHER LEVEL PATTERNS OF TEXT ORGANIZATION OF WORD PROBLEMS	
Semantics/Syntax/Word Identification & Vocabulary Word order	Semantics/Syntax/Vocabulary of mathematical sentences Order of operations, relational symbols, operators Fluency in mathematics
Fluency (Chunking)	Grouping of symbols (relational and operational) with numerical symbols for meaningful computation
GENERATING PATTERNS (ADOPTING SUCCESSFUL STRATEGIES FOR ACTING ON PATTERNS)	
Comprehension	Predicting the organization of word problems Understanding 1) information provided, 2) the expected or anticipated solution, and 3) sufficiency and necessity of the information provided De-Coding written language to En-Coding into mathematics sentences—Building Internal Representation

	Translation of the written text into mathematical sentences based on semantics and syntax.
	Restate the problem in own words—Able to retell the verbal story from the encoded mathematical sentences
ATTAINING A GOAL (KNOWING WHETHER OR NOT A GOAL IS REACHED)	
Metacognition	Metacognition justification and re-solution strategies
Regulation of Text Comprehension	Developing a simpler problem, able to characterize the problem using mathematical semantics and syntax

The Dilemma

Whether it is in mathematics, science, geography or other content areas, learning and applying knowledge requires the coordinated application of multiple reading strategies (Francis, Rivera, Lesaux, Kieffer, & Rivera, 2006). Evidence suggests that many readers experience difficulty in cognitive processes such as making inferences, drawing conclusions, and predicting outcomes; those same processes that lead to successful solutions of word problems. Comprehension levels increase for elementary students when they are taught cognitive strategies through explicit instruction (Sencibaugh, 2007; Swanson, 1999).

Students' conceptual understandings were inextricably bound to their identifying words, understanding of vocabulary, and knowing the text structure (semantics and syntax) (Capraro, Capraro, & Rupley, in press). Cognitive confusion results when students try to apply their general language meanings, which leads to inhibited reasoning. The content is obscured due to multiple meanings of familiar words being applied in a different context of understanding scientific usages (Rupley & Slough, 2010; Slough & Rupley, 2010). It is in the later elementary grades (third through fifth) where degrees of meaning begin to transition from literal, to inferential, and ultimately to conceptual learning. For students to become conceptual learners, they must move into inferential learning where they infer about mathematical ideas within the context of word problems, examine the cause and effect of events within word problems, and determine options for submitting possible approaches to obtaining a solution (Capraro & Capraro, 2006).

Numerous studies of mathematical problems addressed the mental representation of the meaning of word problems; however, little of this work focused on the cognitive strategies students used to distinguish what was relevant from what was irrelevant (Kintsch, 1998; Kintsch & Greeno, 1985; Koedinger & Nathan, 2004; Moreau & Coquin-Viennot, 2003). Reading in mathematics necessitates that one understands the meaning of the words within the context of the word problem. As children learn the vocabulary of mathematics, it is essential they either learn the meaning of new words that are not part of their oral vocabulary or understand the different meanings of words from those that they already know (Rupley, 2006).

Cognitive growth enables students more control over the complexity of word problem solving. Cognitive growth in solving mathematical word problems occurs in stages through representational filters (Capraro, Capraro, & Cifarelli, 2007; Cifarelli, 1998) similar to the acquisition of language through language registers (Mehler et al., 2002). Many students have a tendency to use certain mathematical procedures without considering why the rules and procedures work. These students focus on the computational procedure rather than the conceptual understanding (Thompson, Phillip, Thompson, & Boyd, 1994).

Cognitive strategies appear to mediate learning; therefore, changes that improve the individual cognitive strategy posed promise to influence the sophistication with which students solve complex word problems (Capraro et al., 2007). It is these cognitive strategies that are suspect when students demonstrate mathematical misconceptions (Capraro, Kulm, & Capraro, 2005; Capraro, Kulm, Hammer, & Capraro, 2002). One example would be when students are taught a reading strategy (Mehler et al., 2002) to literally translate word problems. For instance, in a typical problem like: "Ashley is three years older than Kenisha. Write an equation to show how old Ashley is relative to Kenisha's age," students are taught to literally translate the problem. Thus, Ashley is translated into A=3. Students are also taught that "than" sets up a comparison so students continue on the same side of the equal sign completing the sentence resulting in A=3+K, which is a correct representation of the solution. However, when the problem changes to, "Ashley is three years older than Kenisha. Write the equation to show Kenisha's age relative to Ashley's age" with the syntactic properties similar to the previous problem, but a semantic variation, students end up with the same equation (A= 3+K), but in this case, the representation is incorrect. However, students used the literal translation and were unaware of the syntactic difference, which should have resulted in the equation (K=A-3).

In the three examples below we see the same problem, with each supporting the interrelationship of cognitive strategies founded upon reading comprehension and the solution of mathematical word problems (Capraro et al., 2007). In example 1, students using a literal translation scheme may arrive at one of these two possible incorrect solution representations.

Ex. 1 Quentin has some trading cards. Mohen has 3 times as many trading cards as Quentin. They have 36 trading cards in all. How many trading cards does Quentin have?

A) 3X+36=X B) X+3=36

In example 2, the problem is changed to provide syntactic clues without the necessary semantic clues. So again students operating at a literal level find an inadmissible representation for the problem.

Ex. 2 Mohen and Quentin have a total of 36 trading cards. Mohen has 3 times more trading cards than Quentin. How many trading cards does Quentin have?

A) 36 =M3

However, in example three, the syntactic and semantic clues have been aligned to provide the necessary clues that help students' reason beyond the literal translation of word problems. The possible translation is still literal; however, the semantic and syntactic clues are aligned to allow discussion of these and for the teacher to model the solution process that can be used in the previous examples to move toward an implicit decoding scheme.

Ex. 3 Quentin has some trading cards but Mohen has 3 times more trading cards than Quentin. When you add their cards together they have 36 cards. How many trading cards does Quentin have?

A) 3x +x =36

As we have found in our own research (Rupley, 2006; Capraro & Capraro, 2006), that as students transition from reading mathematical word problems for literal information, they begin to develop a mathematics language register. It is through this register that they begin to learn a cognitive process for decoding complex problems and understanding the inter-relationships of words to mathematical symbols (Rupley & Nichols, in press). They begin to form the representational correlations between the word problem and mathematical constructs so they could express them in mathematical symbols (Capraro & Joffrion, 2006; Capraro et al., 2007).

Children may translate English sentences into mathematical expressions, simply moving from left to right without awareness of syntactic and semantic relationships (Powell et al., 2009). For example, "three less than a number" was interpreted by many students as "3 – X", which was really X – 3 since the words "less than" meant to subtract followed the 3. Teachers must be aware of these literal translation schemes and address them through instruction (Lodholz, 1990). Evidence has suggested deeper cognitive reasons for students reversing variables or putting terms in the wrong order. The students in a particular study made an attempt to understand the problem, but were unable to represent their cognitive model symbolically (Capraro & Yetkiner, 2008; MacGregor & Stacey, 1993).

Theory Constructs

An essential feature of the theory we propose is the recognition of the inextricable relationship of the cognitive outcomes for both reading and mathematics. The constructs for each cognitive component of RGA are supported by research demonstrating benefits in reading and mathematics achievement and work together to help students analyze word problems conceptually. This theory, in application, we believe would better enable elementary students to begin to establish a learning foundation that enables them to think about problems less in terms of deriving an answer and more in terms of reasoning about underlying concepts, which is accessed through the reading and understanding of the text mathematically. This intent is pervasive throughout mathematics (Lave & Wenger, 1991; Schoenfeld, 2006; Van Der Henst, Sperber, & Politzer, 2002) and reading education (Fordham, 2006; Pressley, 2002a). The use of principles from cognitive science melds the shared components, skills, and understandings of these two into a theory of great potential for classroom application.

Recognizing Higher Level Patterns of Text Organization Cognitive Components (R) (Syntax/Semantics/Vocabulary & Word Identification/Fluency)

The recognizing higher levels of text organization cognitive components we theorize will positively affect elementary students' achievement on word problems. In particular, we predict that Syntax, Semantics, and Word Identification/Fluency have individual and combined positive effects on the grades four and five students' achievement on word problems.

Research has shown us that syntax (e.g., verb, sentence structure, subject/noun agreement), semantics (e.g., morphemes), and word identification and vocabulary (e.g., repeated readings, rhymes), as shown in Figure 1, are essential cognitive features in word problem solutions (Capraro et al., 2007) just as they are in reading comprehension and understanding (Pressley, 2002a; Smagorinsky, Cook, & Reed, 2005). Reasoning capabilities for these reading skills support and reinforce conceptualization of mathematical word problems. Littlefield and Rieser's (1993) semantic features model of discriminating information advanced the credibility of the paramount importance of these features, and presented evidence that this model fits the discrimination performance of students who are successful at mathematics as well as those who are less successful. Their model demonstrated how successful students analyze the problem text and questions into semantic units, including the actions, agents (persons/things carrying out the action), objects acted upon (these typically correspond to the units of measure), as well as the time and place of actions. Successful students identify relevant information by searching the problem text for information, trying to match the values of semantic features requested in the question with those in the problem text. In contrast, less successful mathematics students were significantly more likely to base their discriminations on surface level aspects of the text such as the *position of information* within the problem statement (e.g., consistently selecting as relevant the first and last numbers). This strategy is almost identical to those employed by readers who have good word recognition skills but lack a cognitive understanding that the purpose of reading is comprehension. They are dealing with the surface or text level features and failing to connect with their prior knowledge to get meaning (Afflerbach, Pearson, & Paris, 2008; Jetton, Rupley, & Willson, 1995).

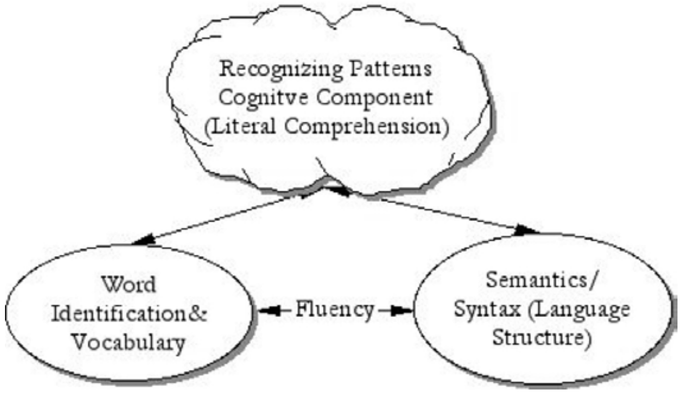

Fig. 1: Recognizing patterns

Example of Pedagogical Features of the Recognizing Patterns Cognitive Component Are Listed Below:

Modified cloze procedures: where students write the correct word in each blank space, solve the word problem and discuss among themselves how the conceptualization was determined by the words/numbers used in the blanks. Such a feature focuses on both the syntax and the semantics of the text and the meaning features and graphic features of their word/number choices. The word choices must not only be correct syntactically, but must also make sense (semantics) in the conceptualization of the mathematical problem. **For example:** The ______boys went to the store to buy candy. Each boy wanted to buy some large candy bars. They had $10.00 to buy their candy. The candy bars were two for ________ or _______for one candy bar. The most candy bars they can buy is ________. The fewest number of candy bars they can buy is _______.

Classification: is associated with all three language features (syntax, semantics, word identification/vocabulary) and can be used to introduce and practice new mathematical conceptual words and to reinforce successful comprehension. A highly successful technique for increasing word-identification abilities that we know should generalize to mathematics is to encourage students individually and in small groups to learn words by arranging them in a word sort. A word sort is a method of sorting word cards into various mathematical categories (such as *sum, how many, total, all together*).

Semantic Clues Categories: enable readers to better understand and comprehend what they are reading in mathematics. These clue categories are essential for conceptualization in mathematics (Mayer, & Hegarty,1996). Johnson and Pearson (1984) classified the major kinds of semantic clues available to readers. A modified listing applicable to mathematics follows:

- Signal words in mathemathics texts are words such as is, are, and combined. Words such as these are often used to alert the reader about equivalencies or operations.
- Synonyms and antonyms. When students encounter unknown mathematical words they can use either synonyms or antonmyns (e.g., subtraction is an antonmyn of addition) with their zone of proximal development to support their problem-solving development.
- Summary statements. Based on connected mathematical story information, there may be multiple solutions, which are defensibile based upon cognitive reasoning.

Morphemes: are essential to understanding text and enabling the conceptualization of mathematical word problems. The Recognizing Patterns cognitive component focuses on teaching students to learn and understand the functions of both bound and free morphemes. Affixes (prefixes, suffixes, and inflectional endings) are bound morphemes that must be attached to a free morpheme or base word. Some common prefixes and suffixes (affixes), base words, and root words can help students learn the meanings of many words encountered in mathematics, (Goldfield & Snow, 1999). For example, if students learn just the four most common prefixes in English (un-, re-, in-, dis-), they will have important clues about the meaning of about two thirds of all English words that have prefixes (Armbruster & Osborn, 2001).

Word Identification & Fluency: Researchers (Rasinski, Rupley, & Nichols, in press; Samuels & Flor, 1997) have identified effective techniques related to repeated oral reading that will be integrated into the development of the Recognizing Patterns cognitive component: (1) students read and reread a text a certain number of times or until a certain level of fluency is reached (generally 80 to 100 words per minute are required to chunk text into comprehensible units for processing); (2) four re-readings are generally sufficient for most students; and (3) oral reading practice can be increased through the use of audiotapes, tutors, and peer guidance. Poetry, rhymes, and songs are especially well suited to fluency practice because they are often short, repetitive, and they contain rhythm, rhyme, and meaning, and can incorporate the use of multiple input channels for processing of text. Two examples showing slightly different levels of mathematics:

Rain, rain go away.
It rained 5 inches yesterday.
Rain, rain go away.
It rained 6 more inches again today.
Rain, rain go away.
It will rain again tomorrow,
    4 more inches is what they say.
Rain, rain go away.
If this is so it will have rained
    ____inches in just three days.
I will never get to play.
It will be averaging
    ______inches of rain a day.

Rain, rain go away.
It rained 5 ¼ inches yesterday
Rain, rain go away.
It rained 3.5 more inches today.
Rain, rain go way.
It will rain again tomorrow,
    3 3/8 more inches they say.
Rain, rain go away.
If this is so it will have rained
    ____inches in just three days.
I will never get to play.
    It will be averaging
    ______inches of rain a day.

Generating Patterns Cognitive Components (G)

The Generating Patterns Cognitive Components we theorize will positively affect elementary grade students' achievement on word problems. In particular, we predict that Story Schema, Comprehension, and Summarization will have individual and combined positive effects on the students' achievement on word problems.

A story schema is a set of expectations about how stories are usually organized (Gordon & Braun, 1983). An internal organization of story knowledge enables readers to process print by retaining story information in memory (see Figure 2) until it makes sense and adding more information as they read. A reader's story schema also is important in that it forms a template for recalling what was read. While narrative materials follow a traditional story structure, expository writing is organized differently. Most content texts are written in an expository/informational style, which results in text that is subject structured, compact, detailed, and explanatory in nature. Mathematical word problem schema is characterized by three basic mathematical components embedded within them (Teubal, 1975): the verbal formulation; underlying mathematical relations; and the symbolic mathematical expression. Word problems can be further analyzed by examining their linguistic properties, their logico-mathematical properties, or their symbolic representations. Linguistic properties included such variables as the number of words in the problem or the mean sentence length (Lepik, 1990). The logico-mathematical properties can be classified in numerous ways, but one scheme is to classify the quantities in the problem into known quantities, the values that needed to be found, and values that may need to be found as intermediate stages of the problem (Verschaffel, Greer, & De Corte, 2000).

Background knowledge, including purposes, has an overriding influence upon the reader's development of meaning (Gersten, Fuchs, Williams, & Baker, 2001). Reading comprehension involves activating, focusing, maintaining, and refining of ideas toward developing interpretations that are plausible (Okolo, Englert, Bouck, & Heutsche, 2007). Thus successful comprehension is an interrelated activation of multiple mental processes (Pressley, 2002b) that originate with the connection of prior knowledge with the purpose of the reading act, which are then interconnected and result in comprehension.

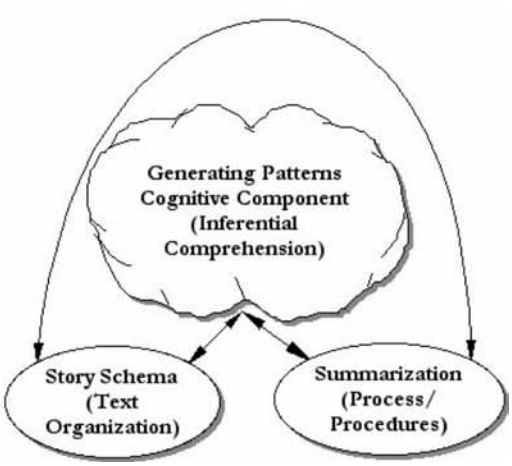

Fig. 2: Generating patterns

In addition, there is a sense in which the reader's comprehension involves two other facets: the reader knowing (either tacitly or consciously) that his or her interpretations for a text were plausible, interconnected, and completely made sense, and, ideally, the reader's evaluation of the transfer value of any acquired understanding. We can view background knowledge as an individual's experiential and cognitive capabilities for (1) written text (word recognition, concept of print, understanding of word order, and understanding of word meanings), as well as (2) the content of what is being read, and (3) how text is organized (Alexander & Jetton, 2000). Activating prior knowledge is especially important in mathematics word problems: ". . . , an effective reader has a clear understanding of mathematical concepts, how they build on one another, and how they are related" (Barton & Heidema, 2002, p. 11).

Examples of Pedagogical Features of the Generating Patterns Cognitive Component Are Listed Below:

Story Schema: (Representation of Reading Plot and Mathematics Plot Relationships) *Starter Event, Inner Response, and Action* (Reading) *Initial State* (Mathematics): Billy hoped to get a bike for his birthday. But he didn't so he decided to make a plan to buy one for himself. He decided to work odd jobs around the neighborhood for 7 days to save enough money to buy his bike. Outcome (Reading) Goal State (Mathematics). On Monday he earned $2.00, on Tuesday he earned $4.00, on Wednesday he earned $8.00, and Thursday he earned $16.00, and on Friday he earned $32.00. Reaction (Reading), Legal Problem-Solving Operators (Mathematics). Did he have enough money to buy a bike for $250.00? Did he have any money left over?

Comprehension: in our theory, comprehension is connected to the two critical components for understanding mathematical word problems (Neufeld, 2005)—prior knowledge and purpose(s) for reading. Questions that have answers within the text information are explicit and referred to as the in-the-book category. This type of question can be used to guide students to realize when the answer is either (1) explicitly stated in the text in one or two sentences (There were 31 ducks on the lake. When the dog barked 10 flew off, how many are left?) or (2) explicitly stated in the text but requires putting together information from several parts. (There were 31 ducks on the lake. Because if was getting colder more ducks were flying south for the winter and flew over the lake. The lake was large and 10 more ducks landed on it. The ducks that landed scared off 3 ducks that were already there. Another flock of ducks flew over and 29 landed on the lake. The farmer who lived close to the lake had a tractor that made a loud noise when he drove it. When he went close to the lake 8 ducks flew off. How many ducks are still on the lake?). Readers must think and search for the conceptual information necessary to understand the word problem when working with upper-elementary and middle-school students by including strategies for identifying information in terms of their prior knowledge of text structure (Raphael, 1988; Raphael & Au, 2005). Knowledge of text structure will help students understand how information is organized and how this knowledge helps to conceptualize mathematics.

Summarizing: Readers who can effectively summarize information can also sort through large pieces of text, distinguish important from unimportant ideas, and bring the ideas together so that the new text represents the original (Capraro & Yetkiner, 2008). The ability to summarize appears to be developmental (Rupley & Willson, 1997). A summary, such as a paraphrase, is a variation of an original passage in one's own words. Summary strategies for reading and mathematics are of paramount importance in reading and conceptualizing mathematical word problems. In reading, the summary demands that readers (1) determine what is important, (2) condense the information, and (3) then put it in their own words. The summary process in conceptual mathematics is identical; however, "putting it in their own words" is deriving from the story the information for solution of the problem. Salient features of summarization include: (1) Identifying the problem in their own words and representing it through writing, drawing, or making a table. (2) Determining the main ideas and connecting them together in a webbing activity, semantic features analysis, or writing activity. (3) Reading and eliminating from the mathematical word problem redundant and unnecessary information. And (4) Remembering what they read by answering summary questions.

Attaining a Goal Cognitive Components (A)

The Attaining a Goal Cognitive Components will positively influence elementary students' achievement on solving word problems. In particular, we predict that Text Organization and Regulated Comprehension of Text have individual and combined positive effects on the students' achievement in solving word problems.

Competent readers monitor their comprehension and know when the process is breaking down (Cross & Paris, 1988). This monitoring of comprehension has been deemed metacognition (See Figure 3). We have learned over the past few decades that good readers are aware of how they construct meaning and apply corrective strategies when they are not constructing meaning (Zimmerman, 1989). Metacognition requires knowing how to achieve the goal that has not been accomplished, as well as knowing when a goal has been reached. The other component of goal attainment is regulation of text comprehension. Regulation of text comprehension is the incorporation or translation of multiple sentences into knowledge units on which they can take some action. In brief, the issue is one of resource allocation during cognitive activity and problem solving.

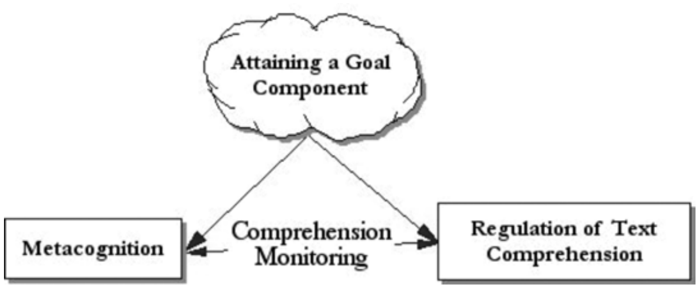

Fig. 3: Attaining goals

Metacognition

Metacognition in the reading domain is a support for working memory in the conceptualization and solution of mathematical word problems. Working memory (where thinking "gets done") receives its contents from two sources, the sensory buffer and long-term memory. The most important aspect of working or short-term memory (STM) is its limited capacity. In general humans can only keep about seven "chunks" of information in STM, and operate on them (Miller, 1950 as cited in Schoenfeld, 2006). Metacognitive strategies provide a buttress for the memory process by feeding back into working memory of mathematical conceptual knowledge that sustains continued progress toward obtaining a solution.

In a comprehensive synthesis of metacognitive research in reading, Pressley (2002b) noted the following: (1) minimal effort is needed to decode words, which frees up a great deal of cognitive capacity for comprehension, for both words and ideas that are represented by phrases, sentences, and paragraphs; (2) cognitive capacity is put to effective use to metacognitively focus on knowing that comprehension is built by relating what is read to prior knowledge; (3) metacognition thus facilitates prediction by the reader about what might be coming up in the text and summarize what is being read; and (4) metacognition used by readers alerts them to when ideas are confusing and how to respond to fix-up strategies, such as rereading, diagramming, searching for patterns, and identifying key concepts carrying words.

Organization of Contents of Memory (Schoenfeld, 1992), taken from Silver (2000), represents the metacognitive, reciprocal relationship of mathematical problem solutions and reading components, which are the stimuli represented by the visual sensory buffer. Reading the word problem activates meta-level processes and mental representations leading to mathematics knowledge and metacognitive knowledge to monitor conceptualization of word problems that lead toward continuous progress to solution of the word problem.

Readers, therefore, must have the ability to monitor their comprehension and know when they have achieved their purposes for reading, when they understand and do not understand what they are reading, and how to correct and regulate their comprehension of text (Sencibaugh, 2007). The same attributes are necessary for conceptualization and solution of mathematical word problems. The instructional components emanating from our theory could be applied to guide elementary students to become aware of what they are doing and why they are doing it. In addition, it supports the development of strategies that model how to check, monitor, and test hypotheses. It provides for them cognitive strategies to monitor their understanding of mathematical word problems and employ and activate fix-up strategies when understanding breaks down.

Example of Pedagogical Features of the Attain a Goal Cognitive Component Are Listed Below:

Text Organizations: analysis of the structure of the text is a means for monitoring comprehension efficacy. Strategies for analysis of text organizations include the following: (1) Draw a diagram or a map of the word problem if it involves distance and/or places. (2) Find a pattern or make a model by skipping around in the text to create a model of the main idea: this may require going back to some information or to read the text quickly the first time and skip ahead to add to the model. (3) Work backwards if the word problem is asking about what happened first or at the beginning of the word problem.

Regulation of Text Comprehension: Those students who have good comprehension are also active and engaged readers (Connor, Morrison, & Petrella, 2004). These readers relate ideas in text to their prior knowledge, construct images, and generate summaries. They do a lot of monitoring with discernment of understanding during reading, enabling them to establish effective recognition of how they process the text. Such here-and-now cognition in the form of active discernment of meaning is always being generated as the competent reader reads with such awareness. Strategies that serve these purposes are: (1) Solve a simpler problem by transforming a difficult or complicated word problem into a simpler problem with similar steps and operations; then, this is transferred to conceptualizing the complicated word problem. (2) "Guess and check" enables the approximation of a solution for a word problem and activates prior knowledge for the elaboration of the process to be applied to the original problem and construct a model for solution. (3) Logical reasoning is used to determine the key concept intended to be conveyed through the "word" in the mathematical word problem.

Discussion

The theory of integrating reading and mathematical constructs represents a unique and logical synthesis across extant reading and mathematics literature. The nexus of reading to learn and the acquisition of mathematics knowledge is a relatively unexplored construct in the elementary grades where reading and mathematical skills lead to either the success or failure of each in later grades. While there may be many other possible constructs on which to build mathematical learning, none seem so plausible as one that combines the literature across reading and mathematics. This construct makes use of ideas originally suggested in the cognitive sciences that propose learning that scaffolds across subject areas increases the rigor and provides richer contexts from which deeper understandings can be fostered.

The integration theory assembles a set of constructs in reading and mathematics that focus on the nexus of reading and mathematics as complementary, interconnected, and interdependent. Mathematics content devoid of context is useless (Adams, 2003). The real-world context for solving mathematical word problems is conveyed in writing, spoken language, and through stories told from one person to another (Boaler, 1999). Mathematical language follows a structure parallel to that learned for reading. Context gives meaning to written words and mathematical sentences. Children must be taught to intertwine reading and mathematical cognitive strategies to make meaning of word problem-solving events. The real-world context for mathematics is conveyed in writing, speaking, and through stories. These basic communication conditions are the link for understanding mathematical language.

It is critical for elementary students to know and understand mathematical language and to develop facility with ***recognizing patterns*** within this language. Mathematics is often taught and uniformly assessed, embedded within dense textual presentations requiring facility with language structure, fluency, and vocabulary. This overarching strategy is important for translating word problems into mathematical symbols for selecting a suitable algorithm. How do children make sense of contextualized mathematical word problems? Some have hypothesized a key word strategy similar to sight vocabulary lists in reading, while others support a decoding strategy, yet others support a broad contextualized reading vocabulary accompanied by strong mathematical conceptualizations and accurate procedural knowledge. One strategy incorporates mathematics literature books to create dynamic and interactive learning environments (Bintz & Moore, 2002; Capraro & Capraro, 2006). While some argue that teacher and instructional characteristics yield promising factors for improving mathematics achievement (Meijnen, Lagerweij, & de Jong, 2003), we suggest an amalgam of strategies synthesized into the cognitive strategy referred to as ***generating patterns***. The use of this cognitive strategy that builds on ***recognizing patterns*** while adding well-known components of predicting, decoding and encoding, building internal representations, and restating serve to create the intellectual structures to bridge into the final hypothesized cognitive strategy.

The capstone of our theoretical model is ***the*** cognitive strategy of ***Goal Attainment***. Goal attainment reflects the ability of students to know what to do and how to do it. In today's society many students have reading and mathematical difficulties. Often arithmetic computation is used as a proxy measure of mathematics learning when in fact naked computation is a poor proxy for mathematical ability and poorly correlated to current trends in high stakes assessment. Comorbidity (mathematics and reading difficulties) compounds issues related to mathematics learning when students are expected to comprehend nuances in either spoken or written communication (Bos et al., 2003). Therefore, students encounter learning conditions that are not aligned with developing and applying metacognitive strategies. The lack of development of the ability to introspectively exam one's own thinking becomes a barrier to being able to make meaningful connections between and among the cognitive strategies.

We believe our synthesis of the existing literature and the resulting analytical and theoretical framework can serve to stimulate introspective and reflective thinking regarding the inter-relationships of reading and mathematical word problem solutions in the elementary grades. In addition, components of the theory can provide researchers with a starting point to pursue more in-depth aspects of the shared features of the cognitive components between reading and mathematics.

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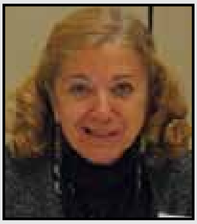

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The Power of Mindset in Shaping Student Success

Megan Webster & Nathalie Bossé

ABSTRACT

The authors explore the assumption that intelligence is static through a case study of one student with special needs, demonstrating how a growth-oriented paradigm supports students. With a growth mindset, teachers can build the necessary confidence for students to risk learning through scaffolding the emotional, social, and cognitive components of learning.

When we first started teaching, Nathalie and I believed that while some students were gifted, others were born with less. Our job, we learned at teacher's college, was to assess the skills and preferences of our students and adjust the curriculum to meet their needs and desires. As we started working more closely with students of various personalities and "abilities," as we thought about it then, our expectations and assumptions began to erode. It didn't take long for us to see students who were "able" fail core courses, while other students—generally hard working, focused, and positive—win academic awards.

Nathalie and I have worked together at an independent school for 10 years, and have borne witness to each other's evolving ideas about student learning and the meaning of "success." Nathalie, with 35 years of teaching experience in French and Student Support, is a mentor to me, Megan, with 10 years of teaching experience in English Language Arts. Many of our expectations—and our misconceptions—about student success were brought into focus when we met an extraordinary student named Sean (all names are pseudonyms). With him we were forced to address, question, and revise our assumptions about teaching, learning, and success; as a result, we set aside our understanding of fixed and pre-determined intelligence and revised our approach to integrating students with learning exceptionalities at our school.

When Nathalie and I read Carol Dweck's *Mindset: The New Psychology of Success* (2006), it helped give words to our growing intuition: People do not (necessarily) succeed because of "natural talent," but because they believe that they can succeed if they work hard. Dweck demonstrates how people who have a growth mindset—those who believe that they can accomplish great things if they work hard and persist—are most successful in school and in life. She asks readers:

> Do people with this mindset believe that anyone can be anything? No, but they believe that a person's true potential is unknown (and unknowable); that it's impossible to foresee what can be accomplished with years of passion, toil, and training. (p. 7)

Sean was one of these students: a student with a passion for stretching himself and sticking to challenging situations even—and especially—when things were not going well. Those with a fixed mindset, on the other hand, believe that their qualities are set in stone, that some people are simply "good at" a particular task, while others are not. As a result, people with a fixed mindset must always prove themselves, fearing that their "natural qualities" might be false. Those with a fixed mindset are loath to try new things in areas of lesser expertise, fearing that they might not be successful. Contrary to popular opinion, Dweck's research has shown that a growth mindset correlates more strongly with success in life than IQ, high marks in school, or "natural abilities" as expressed in a particular moment in each learner's life. Marks and IQ are perhaps better viewed as a snapshot of a student's ability at a particular moment in time, not a stable predictor of ability, as people often think. Dweck has shown that, with coaching, mindsets can change, both over a lifetime and for specific tasks.

Due to a substantial Nonverbal Learning Disability (NVLD), when Sean started kindergarten, our main goal for his education was the development of his social skills. We did not expect him to graduate from high school. His third grade psycho-educational assessment was marked by significant discrepancies between his verbal-conceptual abilities and visual-spatial abilities, suggesting he would need significant support across the curriculum. As a result of his assessment, Sean's educational program was very different from that of his peers: he was paired with a tutor for core subjects, with whom he worked on problem-solving activities in order to continue developing his abstract reasoning without becoming overwhelmed.

Sean had a very challenging profile, but he graduated from high school with honors. How did he do that? How can we cultivate successes for other students with similar learning challenges? In preparing to write this article, we wanted to hear from

Sean, his mother, and his teachers about why Sean might have done so well. He was excited about contributing to an article, as was his mother. One cold afternoon, Nathalie and I met with Sean, his mother, student support teachers, core subject teachers, and tutors from his elementary and high school for coffee and conversation. We recorded our talk for transcription and later analysis. We opened by asking Sean, now in university, about his high school and elementary education. We asked him what he felt helped him grow, and what he thought hindered his growth. After hearing from him, we opened the conversation to the rest of the participants. After our conversation, we organized the transcripts into themes. With some tentative ideas in hand, we met again with Sean, his mother, and his psycho-educational consultant to extend our exploration of the central themes, seek elaboration, and explore counter-examples. Nathalie and I then prepared a first draft of this article that we sent to all of our participants, ensuring we were on the right track. As a result of these conversations, we feel clearer about how a growth mindset shapes one student's outcome.

Like many children with NVLD, one of the biggest challenges Sean faced was managing expected social behavior. He didn't always catch social nuances and often joined conversations with comments that seemed "out of nowhere." Sean struggled with the interpretation of facial expressions and tone from others, and he tended towards monologuing in social situations. He needed help understanding how to adopt an appropriate facial expression, tone of voice, pitch, and volume when he spoke with others. Jane, his mother, helped develop his social skills by making social norms and expectations explicit, exposing the conventions of how to keep a conversation moving forward, wait to speak, and ask for clarification. She and Sean analyzed and debriefed awkward moments so he could better manage future situations. Meanwhile, she surrounded Sean with clear messages of his strengths. At school, we reinforced the work happening at home. While being tutored, Nathalie would often hear Sean's voice rise as he became engrossed in conversations with his tutor. From her office, she would call out, "I can hear you, Seanny!" He would apologize and revert to a more appropriate volume. Over the course of the year, Nathalie had to remind him less often. At the end of a lesson in which he hadn't been reminded to check his volume, Sean would drop by Nathalie's office, inquiring, "Could you hear me today, Nathalie?" Within the year he had internalized the messages and no longer needed to be reminded or check that he was on track. Sean had both the supports to develop appropriate social behavior and the motivation to learn.

Sean could memorize almost anything and he had a highly developed vocabulary. Knowing he had learning difficulties by the time he was three, his parents decided to foster his sense of competence by capitalizing on his talents, teaching him the mechanics of reading and numeracy. Sean quickly gained the genuine respect of his peers in kindergarten because of his extraordinary spelling and mental arithmetic skills. He knew better and longer words than most of his peers, his teachers recall, giving him an air of sophistication. Jane believes that because he started school being acknowledged by his peers as smart, it was easier for him to later accept a curriculum that was very challenging. Research by Immordino-Yang and Damasio (2007) suggests that being perceived as competent by others is a key in allowing the brain to engage in more challenging cognitive domains.

While he could decode fluently from a very young age, Sean struggled to summarize or analyze what he read: he needed a unique approach to the development of his interpretive reading skills. It would be futile to keep asking him to summarize and interpret in the same ways that many of his peers could. For that reason, in elementary school, his tutor would read books one sentence at a time, explaining what happened, what it meant, and what she thought about when she read that sentence. Sean also noticed that when he paced or threw a basketball back and forth with a tutor, parent, or peer, that he was better able to concentrate on complex ideas. As a result, he often threw a ball back and forth with his tutor while she read aloud to him. Though Sean became more adept at summarizing, he still required support with interpretive tasks. In high school, he would have someone read complex pieces of writing with him, and prompt him to record his emergent interpretations. While those written ideas were initially simple, as he reached his senior year of high school, his work demonstrated more age-appropriate complexity and abstraction. While he may always need to read differently in order to understand complex written texts, Sean has surpassed all expectations about his capacity to understand and produce written and verbal abstract thought. While he did not learn to read and write like his peers, he can now certainly demonstrate his understanding, the ultimate goal of any reading comprehension exercise. As Benjamin Bloom (1985) famously wrote,

> After forty years of intensive research on school learning in the United States as well as abroad, my major conclusion is: What any person in the world can learn, almost all persons can learn, *if* provided with the appropriate prior and current conditions of learning. (p. 4)

Teachers at the school worked hard to shape the standard curriculum to meet Sean's particular needs. In middle school, he had a tutor for all academic subjects and did not attend science classes. We assumed it was impossible for him to achieve in that subject while he was working so hard on developing his reading comprehension skills, literary expression, and problem solving in mathematics. At the end of grade 8, Sean convinced us that he could sustain the challenge of the science curriculum so we phased it into his program. During the summer, in order to "catch him up to speed," he worked with a science teacher. By the end of the season, Sean had finished the grade 8 science curriculum. He was so successful that we blended the grades 9 and 10 curricula and he learned it all in one school year; this gave his teacher two years to prepare him for the difficult grade 10 compulsory science course. He surprised us all by getting an "A" on the grade 10 Ministry exam by the end of grade 9. Sean was able to do even more than his peers could do, but he needed to do it with different learning materials and resources. The accommodation of working one on one in a low-pressure context enabled him to overtake his peers by an entire year. These extraordinary results on Ministry exams were evident when he was retested by his educational psychologist. The gap between his verbal-conceptual abilities and visual-spatial abilities had narrowed from a 55-point discrepancy in the previous testing to a mere 17-point discrepancy, surpassing even the most optimistic predictions of standardized IQ testing.

Sean says that much of his motivation to succeed in school stemmed from his desire to learn what his peers were learning. Indeed, research affirms that students are motivated to learn and succeed in school because they wish to engage in the social context of school. They want to be recognized by their peers as competent, and they want to be involved in the school community. Immordino-Yang (2008) at the Mind Brain Institute at Harvard University writes, "We want to know things because we care about them."

Sean achieved a surprising degree of social, emotional, and academic independence by the end of high school. When he was in kindergarten, we never could have imagined that he would graduate from the school on the honor roll in all academic subjects. Jane complains with a smile that he is now so popular she never sees him. He drives a car and has a job. After graduating from CEGEP on the Dean's List, Sean is now studying math in university.

What did we learn from all this? One of the most important lessons for us was rethinking our approach to problem solving, an area of particular challenge to Sean and other students with NVLD. Successful people generally solve problems by using a variety of cognitive and emotional approaches, shaping these approaches in individualistic ways to solve what appears on the surface to be the same problem for everyone. However, when students like Sean are constantly asked to solve problems using only the models provided by the instructor, they often experience nothing but frustrations (Fisher & Rose, 2007; Ablin, 2008). Recent research in neurocognition suggests that teachers must distinguish between task accomplishment and task performance. Research by Catherine Snow (2008) demonstrates how students can achieve high levels of performance when they approach tasks in unique ways and have a flexible time frame. Consider, for example, learning to speak. While most babies will learn to speak by babbling, eventually producing single words and then gradually increasing the length and the complexity of their utterances, some never babble. Many babies start with longer utterances or rely for a long time on gesture before moving entirely to speech. If we put babies in school, there would be no reason to insist that all of them babble first. At the school, we often assessed students' competency acquisition on specific procedures for learning specific tasks; however, the case of Sean helped us better understand how the prescribed procedures can often be obstacles for learning. In order to develop a skill or learn a new concept, Sean, like most students, needed to work it out with varying degrees and kinds of support, and it was important for him to be evaluated on the core competency, not the execution of a particular procedure. His needs for support decreased over time as he became more adept at knowing which procedure to use for a particular problem.

Further, our experience with Sean led us to rethink traditional understandings of early intervention. Traditionally conflated with remediation, early interventions aim to build a student's capacity in a weaker area of cognitive development. The problem with this form of intervention is that it communicates to the child that he or she is not competent, and instills fears that goals may be unreachable. Immordino-Yang and Damasio (2007) have shown how fear can be a deterrent to learning. However, Sean's case demonstrates that one of the most important forms of early intervention is providing children with the opportunity to develop their excellence, so they start school with a confidence in their capacity to grow. From the beginning, Sean has believed that with time and effort he could reach some or all milestones. His parents and educators began to work on developing Sean's weaker capacities only once he felt secure.

While our assumption is that Sean, like all students, can learn and grow given the right social, emotional, and learning conditions, we do not support the axiom that anyone can do anything she sets her mind to. Just because a child believes he is athletic does not mean that he will be able to slam-dunk. Part of being a sensitive teacher is encouraging all students to *grow*, not necessarily to push students to achieve particular outcomes. Our goals for Sean were always growth focused: we never predicted particular outcomes because we had no idea of what the outcomes might be, but we tried to support his aspirations with an open mind.

By witnessing the extraordinary growth of one individual, Nathalie and I now question our assumptions about the "abilities" and "natural intelligence" of our students. We better understand how necessary it is to establish a sense of competence and success through affirming early interventions. We have seen the impact of positive emotional, social, and cognitive support on a child's belief in his ability to grow. We better understand how significant the results can be when the content, process, or pace is modified in order to meet the needs of a particular student. We have observed how a focus on long-term achievement and regular monitoring of progress can also support growth. We now believe that the most important factors for student success are flexible approaches, supportive emotional and social contexts, and an unflagging belief in the ability of all students to grow.

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Nurturing Students' Brains for the Future

Judy Willis

ABSTRACT

As we strive to build a better world for our children and better prepare our students for the complexities of the globalized world they will enter, neuroscience research can be correlated with educational strategies to help us build students' brains to meet that future. An example of the nexus of research and teaching comes from correlating implications from research about memory, cognition, neuroplasticity, and discoveries about the timing of brain maturation with the incorporation of *transfer* opportunities throughout instruction, such that students apply learning to contexts beyond those in which it is taught and rehearsed.

The Highest Brain Processes Most Actively Develop During the School Years

The most complex thinking, reasoning, and innovation-promoting region of the brain is the prefrontal cortex (PFC). Within the PFC are the brain circuits of *executive functions*. These control networks directing decision making and self-control are the last part of the brain to mature, undergoing their most rapid maturational changes during the school years.

Maturation in the brain refers to the *pruning* away of unused neurons and their connections and to the neuroplasticity that strengthens neural networks that are more frequently activated by use. This PFC maturation continues well into the twenties, making teachers critical nurturers of the development of the part of the brain that distinguishes our humanity and defines the qualities students bring with them into their adult lives.

The executive function networks, of neurons connecting together via their branching axons and dendrites, are the control centers of conceptual thinking and highest cognition including critical analysis, judgment, prioritizing, organizing, open-mindedness/flexibility, collaboration skills, induction, deduction, creative/innovative problem solving, and delay of immediate gratification for long-term goal development. It is these highest cognitive, social, and emotional skill sets that are needed for the brain to analyze and utilize the increasingly expanding volume of information that awaits our students in their futures.

Neuroscience knowledge can offer insights to help us guide students' prefrontal cortex development while we also contend with the demands that they "learn" an already over-stuffed curriculum that keeps expanding beyond appropriate teaching limits in response to more available information. Anyone involved with administration or classroom instruction knows that promoting students' rote memory of an over-stuffed curriculum is inadequate preparation for them to build the skill sets they will need to accurately assess, as well as innovatively use, the growing surge of new information and changing "facts" (remember when Pluto was a planet?).

As we strive to prepare students for the 21st century, with problems and opportunities not yet recognized, the development of executive functions such as judgment, flexibility, and critical analysis take on even greater significance. Before Copernicus recognized that the earth revolves around the sun, the accepted "fact" was that the sun orbited the earth. Students need to have guided experiences evaluating validity of information and applying learning to tasks beyond their original learning framework to be prepared to take optimal advantage of the current and future expanding funds of knowledge and changing "facts."

Consider that 30 percent of today's jobs did not exist 20 years ago. Success in jobs of the future will not seek out candidates with the limited perspective of rote memorization of the increasing volume of facts, when facts as we now know them will be revised or disproved in the future.

If students leave school without the skill sets of executive function activated during their critical prefrontal cortex maturation years, their expanded volume of memorized facts will be inadequate preparation for the challenges and opportunities of the 21st century. They will not be prepared to enter careers where they will need to apply executive functions to evaluate, understand, and innovatively apply the advances in technology and global communication to the exponentially growing information base.

Preparing Brains for the Future With *Transfer* Opportunities Now

The developing neural networks of executive functions (EF) in the prefrontal cortex can and must be activated and strengthened by *use* if students are to reach their maximal potentials for these highest cognitive, social, and emotional skill sets. Teaching children while the PFC is undergoing its most rapid development from ages 8-18 is challenging when rote memorization takes up much instruction time. However, you can promote EF activation by incorporating, into learning and assessment, opportunities that allow students to process, evaluate, and ultimately transfer new information and procedures to applications beyond those in which they are learned.

Transfer opportunities, embedded in curriculum, assessment, and lesson instruction build up neural networks of memory storage throughout the brain's cortex and also exercise the developing networks of executive functions in the prefrontal cortex. Transfer of learning to novel situations provides opportunities to mentally manipulate new learning to solve new types of problems. Through *neuroplasticity,* transfer activities extend the boundaries of memory storage beyond isolated circuits in which the brain holds information that is only passively learned and drilled into memorized facts.

When a memory circuit is activated, information is conducted from neuron to neuron by electrical flow. Neuroplasticity strengthens active networks in response to their increased electric flow. The components of neuroplastic growth include thicker myelin insulation around the axons that carry information from each neuron on to the next and more connections among the memory circuit's neurons (more dendrites and synapses). These changes result in faster speed of information transfer, more rapid memory retrieval, and greater memory durability so the network is less susceptible to the pruning of disuse.

In addition to stimulating the neuroplastic development of the rapidly maturing prefrontal cortex networks, transfer tasks can increase long-term *conceptual* memory storage. Transfer learning opportunities can be designed so students use executive functions and activate previously unrelated memory circuits of facts for use *together in new applications*. This simultaneous stimulation, of previously unconnected circuits of stored information, promotes growth of connections among these circuits as the *neurons that fire together, wire together*.

Simultaneous activation of previously isolated memory circuits (such as rote memorization of mathematics formulas or content-specific vocabulary words) for use with other memory networks to perform new tasks promotes the neuroplastic changes that incorporate the rote memory circuits into larger circuits. These interconnections transform the isolated memories, which previously were only activated by the specific stimuli with which they were learned and practiced, into relational *concept memory circuits*.

Through incorporation of new learning into the larger related neural networks of concepts, the new learning will not become an isolated, unused neural network that will be pruned away after test prep is over. Connected relational concept networks become the expanded funds of applicable wisdom that executive functions can access far beyond the school years. These memory concept networks, along with the strong circuits of the executive functions needed to apply the knowledge they hold, are the skill sets needed for their future critical analysis, creative problem solving, and innovation. The physical construction of the networks of executive functions and conceptual memories will prepare today's students to solve problems not yet revealed and benefit from the opportunities that will be provided by information and technology not yet developed.

Motivating Engagement and Perseverance

When students know the information they are being asked to learn will be used to create products or solutions to problems that interest them, the new learning and its practice are valued because they *want* to know what they *have* to learn. The expectation that new learning will be applied to desired goals increases the strength of memories through their association with positive emotions. Transfer tasks, that are planned so students can engage through strengths and interests to achieve goals they consider relevant, are powerful learning motivators and memory enhancers.

An example of transfer for the multiple purposes of motivation, conceptual long-term memory, and executive function mental manipulation is *project-based learning* with multiple options of approach and solutions. To promote the requisite learning goals and the activation of the rapidly changing networks of executive function, transfer activities should be designed to require several of these functions such as judgment, prioritizing, organizing, communication, collaboration, induction, deduction, prior knowledge activation, and/or prediction. These learning experiences then serve to motivate participation and to promote critical analysis and goal-planning as well as flexible, divergent thinking.

Cross-curricular project-based learning further increases the opportunities for transfer and student motivation. Robotic design is an example using physics, biology, engineering, math, Internet research, economics, language arts, and graphic arts that also incorporates real world problems, student interests, and offers a variety of opportunities to contribute through individual strengths in collaborative group projects. Robotic limb replacement or mechanical enhancement of healthy arms and legs could link the need for such devices by people who have lost limbs in battle (current events/history) with student interest in sports. Students can choose to work on robotic limb replacements that could theoretically provide physical enhancements relevant to their own high interest sports, such as jumping higher to get more "air time" for skateboard or snowboard maneuvers.

Teachable Moments Into Transfer Tasks

The concerns and complaints of students can be noted and subsequently incorporated into projects using transfer of learning. For example, students may voice their frustration regarding the extra time it takes to get to school because of a series of new traffic lights. A look at upcoming units of study might include causes and interventions regarding pollution in science and the solving of single variable equations ($3X + 1 = 7$) in math. A project can be planned that connects the required learning with students' real life concerns. They could be given the opportunity to use the requisite math and science to accumulate data and formulate interventions to achieve their personally desired goal (shorter drive time) and a desirable community goal of cleaner air.

Some students may predict that the timing of traffic lights can be synchronized to reduce idling time of the greatest numbers of cars, limit delay, and reduce polluting emissions. They might further consider the requirements for adequate frequency and duration of "go" time at these intersections for safe crossing by pedestrians of all ages and physical abilities.

Because project tasks are planned in advance, such that students apply learning from the unit of study as they investigate and plan, the information they are required to learn becomes knowledge they want to acquire. Now they approach instruction with personal interest as they value the knowledge. The varied options and new applications of the ongoing learning provided by the transfer to the new applications of the project thereby increases motivation while promoting executive function activation.

Further authenticity of goals, along with opportunities for students to build literacy and communication skills, are promoted when transfer tasks are designed to include interviews with experts, especially those with different perspectives so they can exercise their information analysis. Motivation is enhanced from preparation of project information for an authentic "audience" such as a proposal for local government in writing or at a public hearing, letters to the local newspaper editor, or presentations to invited professionals who come to the class to hear, view, and respond to students' proposals.

Feedback

As a survival imperative, the mammalian brain responds with increased attention to feedback about the accuracy of predictions/choices it makes. Further, through a dopamine-prediction reward circuit, this feedback results in increased memory consolidation. Ongoing formative assessment and feedback by teachers, teacher-guided peer feedback, and opportunities for self-reflection and revision further promote executive function activation such as judgment and goal-directed behavior.

Transfer activities should be planned to offer students feedback about the outcomes of their predictions as well as opportunities to recognize the positive relationship between their effort and goal-progress. The amount of guidance, scaffolding, or increased challenge provided in the feedback can be varied as a way of differentiating for the range of student needs or mastery.

Giving students' networks of executive functions cognitive workouts, during their most stimulation-responsive growth phase, is both the privilege and responsibility of all educators. The nurturing of these cortical circuits during their most active developmental phase impacts the cognitive resources students bring with them into adulthood. Today's classroom interventions are the powerful neurological tools with which we can help all students embark on their futures with their highest potentials for social, emotional, and professional fulfillment.

The Future

Transfer learning experiences that incorporate executive functions will go far to promote students' "higher processing" as they construct the powerful concept networks needed for accurate and flexible analysis and utilization of future information. Students' concept-constructed long-term memory may first be evident in their more accurate "predictions," such as response to test questions that are not identical to the homework problems they practiced.

These same brain networks will grow and ultimately guide these students to make the wisest choices in work and social situations, and ultimately to use creative innovation to find the most successful solutions to future problems. These students will have the neural architecture and experience to solve the problems as well as participate in the opportunities that await them in the 21st century.

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