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The ENGRAMMETRON: Establishing an Educational Neuroscience Laboratory

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This article chronicles the background, conception, design, and development of the ENGRAMMETRON, a new Educational Neuroscience Laboratory in the Faculty of Education at Simon Fraser University, established for new opportunities and directions in educational research.

INTRODUCTION

A year ago, EDB7504, a small classroom previously designed for observational research, and subsequently used for small classes and occasionally for evening graduate seminars, otherwise stood empty. Today, it is a state-of-the-art educational neuroscience laboratory that has come to be known, for reasons presented below, as the ENGRAMMETRON.

The ENGRAMMETRON is an unprecedented new educational research facility for simultaneously acquiring a full suite of behavioural, psychometric, and psychophysiological data, including audio, visual, textual, keyboard and screen capture, eye movement, brain waves, heart rate, skin conductance and temperature, and so on, and in an manner suitable for integrated analysis and interpretation.

A Canada Foundation for Innovation (CFI) New Opportunities Grant, with support from the British Columbia Knowledge Development Fund (BCKDF), and Simon Fraser University (SFU), provided funding for ENGRAMMETRON infrastructure. The question naturally arises, how did such a facility for educational research come to be? In this article, I provide some background in this regard, and discuss how this innovative facility came to be conceived, designed, and developed.

A major part of this initiative involves working toward a definition and understanding of educational neuroscience, justifying why such a new branch of educational research is warranted, and exploring what is involved in terms of theories, methods, and practice. Toward this end, some projects and initiatives already underway and others that are anticipated are also presented.

ORIGINS

How and where an idea initially begins is difficult to determine, although its origins are easier to recognize and reconstruct once it has come to fruition. Typically these origins are plural, dynamic, and intertwining, rather than singular in nature.

Part of the groundwork for this initiative came from my own background, interests, and experience. My early aspiration, as an undergraduate with a deep interest in the nature of consciousness, was to pursue a career in neuroscience. Accordingly, I enrolled in a "pre-med" program. Through the course of my studies, however, I became enchanted with philosophical and mathematical aspects of mind, and graduated with majors in those disciplines instead.

Having been raised in the oil and gas industry, I kept one foot in the exciting and computationally demanding area of geophysical data processing, and especially, seismic imaging (Claerbout, 1985). Being engaged in using acoustic energy to explore for and to reveal ancient geological structures conducive to trapping hydrocarbons amply demonstrated to me the profundities of mathematical modeling and its applications. To this day, I think of seismic imaging, along with other forms of imaging, such as brain imaging, as social constructions of new senses of perception (Campbell, 2001). I worked gainfully in that industry until the mid-eighties, until I witnessed a long anticipated fully three-dimensional seismic imaging technology become a reality. Then I moved on.

Whereas in seismic imaging, computational mathematics provided us with a new sense of perception, I became enthralled with developments in artificial intelligence (AI), and the implications of using logic to model higher cognitive function. Working as a knowledge engineer, however, I found expert systems technology, the hallmark of AI, with its emphasis on well-defined rules working with well-defined objects, to be insufficient for working with real-world objects, which are typically identified with perceptually-based criteria. For me, this realization mirrored the classical philosophical problem of reconciling perception and intellect, and pointed me to the importance of pattern generation and recognition. With this problem in mind, I embarked upon graduate studies in philosophy, with a focus on connectionist systems (McClelland, Rumelhart, et al, 1987) and neurophilosophy (Churchland, 1984). How to develop a neural net capable of both perception and logical inference? Surely there is an answer to this problem. There is already, after all, what we call in mathematics, an existence proof: The human brain.

I was not so much interested in how to make a machine do something that humans can do naturally, or at least something humans can learn to do. Rather, my desire was to understand how humans are able to do, and learn to do, these things. Understanding the relation between perception and intellect is a tremendous task, but I now felt as though I had an entry point into this great grand problem: How do we learn to recognize and generate patterns, viz., mathematical patterns?

Eventually, I found a perfect home for seeking answers to this question in mathematics education research into learning and teaching elementary number theory. Like seismic imaging, there are practical implications in answering questions like this. Understanding what we are looking for, what we are looking with, why we are looking, and knowing when we have found it, are all crucial aspects of teaching and learning, which affect any form of research for that matter. Most graduate geophysicists I recruited and trained in industry could do the math involved in seismic imaging, but surprisingly, most of them had little understanding as to what the math was doing.

Mathematical perception and cognition take place foremost in the minds of learners (Campbell, 2003a). Insofar as human minds require human brains, it follows that we stand to gain important empirical grounding for our models of cognition and learning by imaging brain and brain behavior. Not calibrating our cognitive models of learning and understanding to brain and brain behavior, strike me, prima facie, as much like drilling for oil and gas based on surface geological features alone.

This realization hit home for me with full force in the course of my mathematics education research when I first captured an "aha!" moment (Campbell, 2003b). To that point, I thought I had done everything I could to record this phenomenon. I was excited, but remained deeply unsatisfied. So far as I was concerned, I was only observing and scratching the behavioral surface of a much deeper and profound mental event, one I felt must be manifesting itself in some way in brain and brain behavior. Thus, when the CFI provided me with the means and opportunity to make such observations, combined with support and encouragement of faculty and administration both within Education and in other departments, such as Psychology and Kinesiology, I felt compelled to pursue them.

EDUCATIONAL NEUROSCIENCE

The cognitive neurosciences have become increasingly successful in correlating cognitive processes and functions with brain and brain behavior (Gazzaniga, 2004). Brain imaging has played a key role in this success. Brain imaging tools fall into two main categories: hemodynamic and electromagnetic. The former category includes functional magnetic resonance imaging (fMRI) and positron emission tomography (PET); the latter category refers to magnetoencephalography (MEG), electroencephalography (EEG), and more recently, infrared optical imaging techniques. These tools all have their strengths and limitations, and cautionary notes regarding their use for the purpose of mapping cognitive function X to brain structure Y are also in order (e.g., see, Sarter, Berntson, & Cacioppo, 1996; Uttal, 2001). The relations between mind and brain can be much more dynamic than that (e.g., Penny, Kiebel, Kilner, & Rugg, 2002).

Some educational researchers have been collaborating with cognitive neuroscientists to apply these tools and their associated methods to educational questions (e.g., Schwank, 1999), and some cognitive neuroscientists have been turning their wares to educational matters of their own accord (e.g., Goswami, 2004). It is important for educational researchers to collaborate with cognitive neuroscientists, not only to learn about new theories, methods, and results, but also to gain experience with new equipment and tools. A drawback here is that the availability of these tools remains subject to the priorities and interests of others (e.g., Schwank, 1999). For those cognitive neuroscientists who do turn their expertise to educational research, their assumptions, motivations, and goals may not necessarily accord with those of educational researchers. Educational research depends largely on granting agencies. As brain imaging techniques become more effective in the study of cognition and learning, educational researchers who do not have ready access to or experience with these new methods and tools may be at risk of losing future funding opportunities, and hence, losing research opportunities to researchers from other disciplines that do. Educational neuroscience, by adopting and incorporating advanced new tools and methods, seeks to empower educational researchers with new means by which to define their own priorities, while maintaining their own traditions, assumptions, motivations, and goals.

There is a sense in which educational neuroscience can be seen as an applied cognitive neuroscience. Forensic science is another area that is rapidly adopting and applying tools and methods of cognitive neuroscience. Although there is much merit in viewing educational neuroscience as an applied cognitive neuroscience, this may also be seen as a limiting view, and one that may not serve educational research particularly well. There is much more to consider than this, and I shall endeavor to do that now.

John Bruer (1997) famously argued that the gap between neuroscience and education was "a bridge too far." Yet, in that article, Bruer also identified cognitive psychology as being the one discipline where these two large fields would be most likely to find common ground. Since that time, informed by lesion studies and equipped with advances in brain imaging, cognitive neuroscience has emerged in large part through interdisciplinary conjunction between the neurosciences and cognitive psychology. Educational psychology also has interdisciplinary connections with cognitive psychology, and those connections have proven quite fruitful. Educational neuroscience can be seen as a new interdisciplinary area of research emerging through the conjunction of educational psychology and cognitive neuroscience.

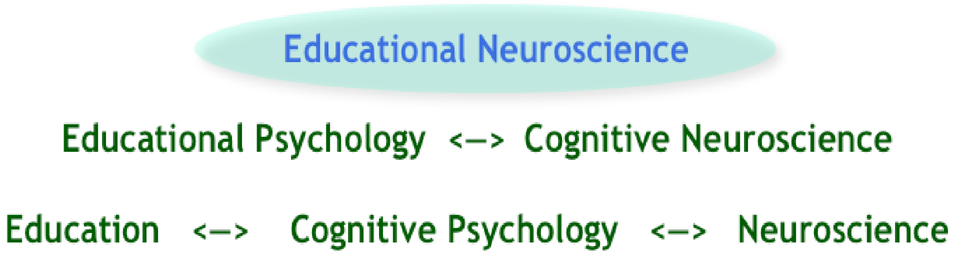

Fig. 1: Building interdisciplinary links

Even so, educational neuroscience can still be viewed as an applied cognitive neuroscience, and I am fine with this, so long as applying methods of cognitive neuroscience are concerned. Furthermore, educational neuroscience should be informed by and, in many cases, even guided by results from cognitive neuroscience. It is a different story, however, when it comes to forsaking the more humanistic and phenomenological frameworks that have gained hard fought ground in educational research over the years. Cognitive neuroscience is concerned with neural mechanisms in relation to cognitive function. Educational neuroscience, however, to be more than just an applied cognitive neuroscience, has a license to prioritize the lived experience of learners, and to treat body, brain, and brain behavior as manifestations of that experience.

EMBODIED COGNITION

How, though, to justify the claim that the lived experience of cognition and learning, not only is, but must be manifest in body, brain, and brain behavior in some way. It is not obvious that this need be the case, and, if so, it is not evident in what ways.

Traditionally, mind and body, and thus, in particular, mind and brain, have been understood to be two qualitatively distinct ontological substances (viz., *res cogitans* and *res extensa*). Material things can be objectively observed and measured, whereas mental things can only be experienced subjectively. Consequently, mind and brain have traditionally been studied separately, and attempts to account for how the two relate have been deeply problematic. Indeed, some traditions, most notably behaviorism, have gone so far as to deny or bar the immediately evident lived reality of mind from scientific study altogether. Other traditions, such as phenomenology and constructivism, have taken this subjectivity to be the radical empirical grounding of any observations or theories laying claim to objectivity.

It soon became evident to behavioral psychologists that not all things human could be understood in terms of stimulus and response. With the emergence of cognitive psychology, it has become much more commonplace to account for human behavior by introducing cognitive processes and functions to mediate between stimulus and response. What has been at issue is the nature of these cognitive processes and functions. Three major paradigms have emerged.

The "symbolic paradigm," which took hold in the fifties and sixties (Gardner, 1985), portrays cognition in terms of symbolic constructs pertaining to memory, attention, reasoning, and so forth. These symbolic constructs were particularly amenable to modeling cognitive function with the rule based reasoning software, noted above, that came to be known as expert systems.

The "connectionist paradigm" emerged simultaneously with the "symbolic paradigm" (ibid). This brain-based paradigm emulates the interconnected nature of neurons. It was largely discounted until the eighties, when connectionist "neural net" technology proved its worth in pattern recognition applications.

Although both the symbolic and connectionist paradigms focus on modeling cognitive processes and functions, they differ in their respective orientations toward mind and brain. Moreover, it would seem, the lived experience of human beings, as a designated focal object of study, remains largely inconsequential to both.

Despite all their benefits, these two paradigms are driven by what can be seen as ontological and epistemological biases that discount the immediate reality of consciousness that all human beings typically partake in. It is no coincidence that this immediate reality is difficult, if not impossible, for these paradigms to account for, given that consciousness does not factor into either, per se.

Another way of saying this is that these paradigms are purely natural and analytic in their orientation, and do not account for the phenomenological (Campbell, 1999, April), either epistemologically in the sense of Husserl (e.g., 1962), or ontologically in the sense of Heidegger (e.g., 1972). Fortunately, in the nineties, a third paradigm emerged seeking to provide a coherent and unified foundation to both the natural and the phenomenological: The “embodied paradigm”, or “enactivism”.

Drawing on Merleau-Ponty's (1962) notion of double-embodiment, where the living body is taken as a single ontological primitive encompassing mind and brain, Varela, Thompson, and Rosch (1991, p. xv) proposed a view of cognition as embodied action:

> We hold with Merleau-Ponty that Western scientific culture requires that we see our bodies both as physical structures and as lived, experiential structures — in short, as both 'outer' and 'inner,' biological and phenomenological. These two sides of embodiment are obviously not opposed. Instead, we continuously circulate back and forth between them.

This circulating notion of double-embodiment, to draw upon some Husserlian-Heideggerian terminology, captures, on the one hand, our natural sense of "being-in-the-world." When we take this "natural attitude," we attend to things as being outside of ourselves, and think ourselves as being part of a greater whole. On the other hand, when we "bracket" this natural assumption, and just take our experience for what it is, in its lived immediacy, we attend more to the reality of being-in-itself. In this "phenomenological attitude" there is a sense in which being is in us. Thus, taking this latter attitude, our focus can turn to the immediate reality of being itself.

If, then, we take the living body as the ontological locus of both the natural and phenomenological attitudes, we can then think ourselves as being (in part) the world-within-itself (Campbell & Dawson, 1995). This insight leads us to a much less alienating view of constructivism (Campbell, 2002). It also helps us to understand that our relation to the world is much more intimate than we have typically supposed it to be (Campbell, 2001, 2003a).

As educators, or so it seems to me, we should place as much humanistic emphasis on understanding the real lived experience of learners as we do with scientific hypothesizing about their thinking. The symbolic and connectionist paradigms essentially reduce lived experience to mere processes and functions. In keeping the lived experience of learners in mind, the embodied paradigm provides a distinctively educational approach for research into the full dimensionality of learners and learning. The embodied paradigm unifies mind and body such that that an educational neuroscience can augment the symbolic and connectionist paradigms with phenomenology in a unified study of mind, brain, body, and behavior.

The embodied paradigm provides justification as to why an educational approach to research that includes a neuroscientific study of brain and brain behavior is warranted. The embodied paradigm not only reminds us of interdependencies between mind, body, brain, and behavior, it also helps us to see the importance of studying these different aspects of human beings in tandem. A fundamental entailment of the embodied paradigm is that changes in lived experience manifest in some way through changes in brain and behavior, and vice versa. Educational neuroscience is concerned with identifying and establishing valid and reliable connections between these natural and phenomenological orientations.

It is important to emphasize, however, that such an approach would not be possible had significant and substantive progress not all ready been made in this direction. Drawing on decades of work in psychophysiology and the neurosciences, guided by the symbolic and connectionist paradigms, and building on technological innovations in brain imaging, such progress has been and is rapidly continuing to be made in cognitive neuroscience (Gazzaniga, 2004).

THE ENGRAMMETRON

The laboratory I have been granted CFI funding to establish in the Faculty of Education at Simon Fraser University is, then, both by conception and design, an educational neuroscience laboratory. This laboratory will serve to further my own research agenda in mathematics education research. In the most simple sense, I wanted a facility that would enable me to capture the "aha" moments of concept formation that I mentioned earlier with as much observational detail as possible. Beyond that, in recognizing the uniqueness of this facility, and the potential implications of educational neuroscience in contributing to the on-going and future vitality of educational research, it was important to gear the lab up for high production research with other colleagues interested in this approach.

Thus, with such collaborations in mind, I also applied for and obtained a Social Science and Humanities Research Council (SSHRC) Strategic Research Cluster Development Award for an Educational Neuroscience Group for Research into Affect and Mentation / in Mathematics Education (ENGRAM/ME), designating my lab as the central hub for this new Strategic Research Cluster: hence, the ENGRAMMETRON.

The ENGRAMMETRON was designed and constructed mainly in the 2005/2006 academic year. The two main design principles were flow and functionality, inspired by the aesthetics of Feng Shui and Bahaus, respectively. Figure 2 illustrates the final layout of the lab. North is to the top of the diagram.

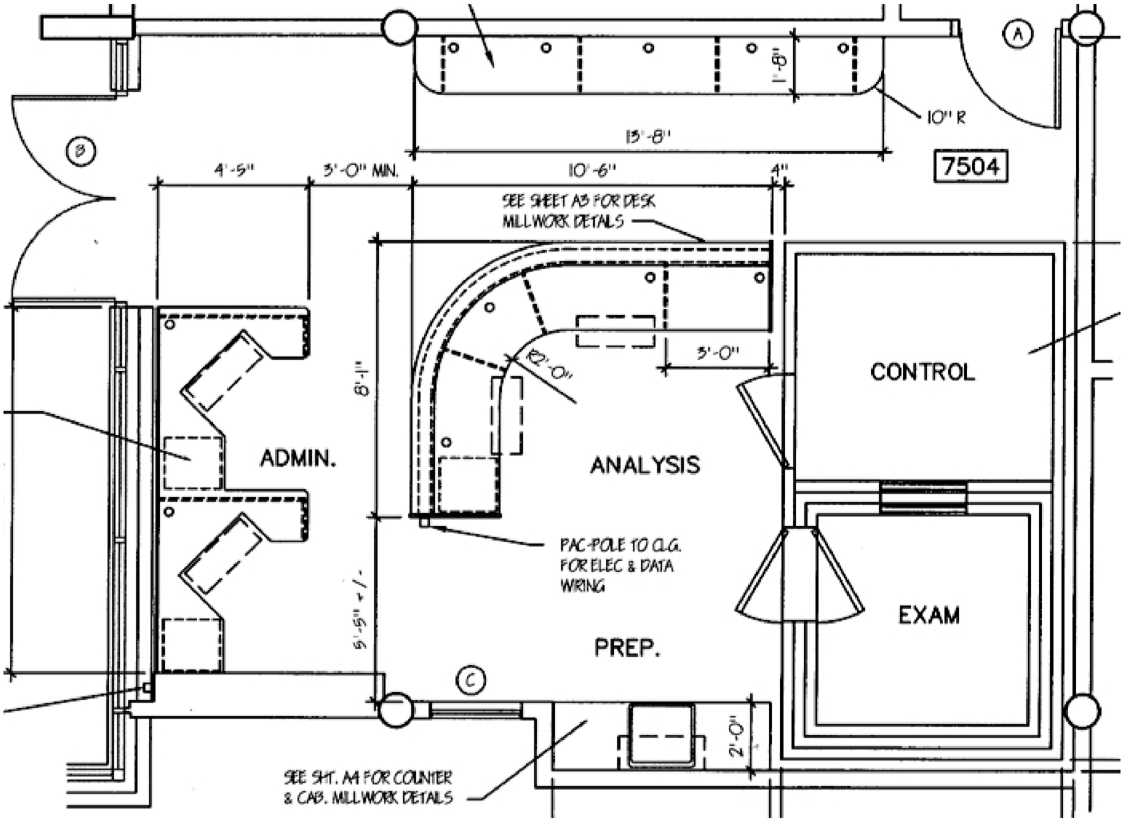

Fig. 2: EDB7504 Final Layout

The lab, in EDB7504, is located on the 7000 level of the Education Building, directly beneath the zen garden, with the main entrance at the northeast corner, and a double door exit on the west side. Immediately upon entering the lab, there is a space designated for a bank of computer stations along the north wall. These computer stations are for graduate students and other colleagues working in the lab. These computer stations will serve for things like conducting literature searches, learning software and analysis techniques, writing up results, and so on. In the northwest corner is the waiting and rest area, mainly for volunteers participating in our research.

There are two workstations along the west windows, designated as the administration area. The northern most workstation is for providing and gaining informed consent from our participants, along with collecting psychometric data from them and analyzing those data. The southern most workstation is for coordinating the activities in the lab, paying bills, scheduling and designing experiments, ordering supplies, and so on. Once the psychometrics have been obtained, participants proceed to the preparation area along the south side of the lab, where they are "wired up" with electrodes for obtaining psychophysiological measurements. Along the east side of the lab is a double room audiometric suite. This suite attenuates acoustic and electromagnetic noise that could otherwise interfere with our measurements. It is in these rooms that experiments are conducted and data acquired. The southern most room is where our participants are directed once they have been "prepped." Here they will be engaged in various activities while being monitored in various ways from the northern most control room.

Once experiments have been conducted and data acquired, the data need to be analyzed and integrated with the psychometric data for interpretation. These activities occur in the analysis area, which constitutes the centre point of the lab.

The motivating idea for this layout was to optimize production efficiency, allowing each of these activities, from literature searches, informed consent and psychometrics, to participant preparation, data acquisition, and analysis and interpretation, and write up, to be occurring simultaneously. In this way, a production research pipeline, of sorts, becomes possible. The ENGRAMMETRON is equipped with state-of-the-art technology for data acquisition, analysis, and interpretation. The most notable pieces of equipment are the BioSemi EEG units, of which there are two. Each of these units can currently record 64 channels of EEG (each being expandable to 256 channels), simultaneously with other psychophysiological data sets like electrocardiograms (heart rate), electromyograms (muscle movements), temperature, respiration, and skin conductance.

Computer-based stimuli and interactions are presented and recorded using a Tobii eye-tracking monitor. This monitor has built in infrared emitters and detectors, which allow participant eye movement, gaze, and pupil dilation data to be acquired in a transparent and non-obtrusive manner. In addition to these psychophysiological data sets, high quality audiovisual data from two broad-spectrum cameras and one highly sensitive microphone are also acquired. All of these data sets are recorded simultaneously (Please view Supplementary File -- Movie: Eye-tracking and EEG data acquisition).

This movie segment illustrates data collected, rendered, and integrated in a time synchronous manner in the ENGRAMMETRON. The paradigm in this case is from Dehaene, Izard, Pica, & Spelke (2006). Although Dehaene, et al, used this paradigm to explore the question as to whether there exists a core set of geometrical intuitions that are universal to humans independently of cultural considerations, we are using it as a means to gain insights into mathematical pattern recognition, image-based reasoning, and concept formation. In this case, the participant had already run through the paradigm, which consists of 45 slides, twice in this session, and what is illustrated here is his third run through. In his first run through, he simply attempted to identify which of the six diagrams in each slide did not "fit" with the others (for each slide, a geometrical concept unites five of the six diagrams, but not the other). In the second run through, he was asked to talk aloud about his thinking in the first run through. In this third run through of Slide 22, he was asked to attend to the uniting concept (in this case "diagonals"), and to comment on how that information would have affected his thinking with respect to his previous run throughs.

Evidently, this excerpt indicates the recording of an "Aha!" moment, and helps illustrate the rich kinds of data sets we can obtain for analysis. A key component of the ENGRAMMETRON is the software used to acquire, analyse, integrate, and interpret the various psychometric, psychophysiological, and behavioural data sets acquired in the lab. Most notably used here is Noldus's Observer XT software. This software initiates and coordinates data acquisition, ensuring all the various data sets can be time synchronized, and subsequently enabling integrated coding and interpretation of these data sets.

Between data acquisition and interpretation, however, falls data analysis. In this regard, we use Tobii's Clearview software to analyze the eye-tracking data and render the results to a video file that can then be imported to the Observer XT. Likewise, we use Megis's Brain Electrical Source Analysis (BESA) for analyzing the EEG data sets, and render the results to an ASCII file that can then be imported to the Observer XT.

Other software we have available for data analysis include software to help determine emotional states from facial features, along with multivariate and matrix analysis software for data mining and pattern detection in large data sets.

Because acquired data sets are well into the gigabyte range, and because the analysis and interpretation techniques are so computer intensive, it is important that the lab have as much computing power as possible. To this end, the latest in multi-core computer systems and database storage technology are being acquired as needed.

ENGRAM/ME

As noted above, the ENGRAMMETRON is serving as the central hub for a SSHRC Strategic Research Cluster called the Educational Neuroscience Group for Research in Affect and Mentation in Mathematics Education (ENGRAM/ME). Here, the backslash indicates that mathematics education research is being used, again, as the thin edge of the wedge, so to speak, for a more general and inclusive collaborative program of research in educational neuroscience.

That is to say, research conducted in the ENGRAMMETRON is not restricted solely to research in mathematics education. ENGRAM/ME members currently number around 40, involving educational researchers from within the Faculty, from other disciplines within Simon Fraser University, such as Psychology, Kinesiology, and Biomedical Engineering, and other universities, both within Canada and beyond. ENGRAM/ME also includes professional associations and industry partners.

Thus far, there have been a variety of collaborations struck, and ground-breaking work is underway in areas such as signal processing for EEG and image analysis, educational technology, notably with Phil Winne's gStudy group, David Kaufman's SAGE group, along with a variety of other initiatives with colleagues from Stanford, UBC, University of Illinois at Urbana-Champaign, and elsewhere. The ENGRAMMETRON also has a virtual presence on the world wide webat <www.engrammetron.net>, along with a sister website currently underdevelopment for ENGRAM/ME <www.engramme.net>. Future plans for dissemination of information and research and include a quarterly newsletter and on-line journal. An important facet of ENGRAM/ME's work is outreach. To that end Kate Patten, the lab's outreach coordinator, has set up an outreach folder on the ENGRAMMETRON website, replete with information and helpful links about matters of concern to educational neuroscience. Jake Stone has been developing an ENGRAM/ME WIKI to serve as a means for generating an interdisciplinary and collaborative critical mass.

LAB ACTIVITIES

Other individuals have been involved in helping me get the ENGRAMMETRON off the ground. Stan Kanehara has brought his expertise and savvy to bear on the day-to-day administrative details. Arlene Robb has maintained some semblance of order in the esoteric demands of grant management. The contributions of these two stalwarts of the Faculty coming out of retirement to assist in this venture have been invaluable. Moreover, a venture of this kind cannot be any more successful than the undergraduate and graduate students involved in helping to make it happen. I have had the pleasure and good fortune of working with some exceptionally talented and motivated individuals. There are a number of key components involved in the day-to-day operations of the ENGRAMMETRON, and these individuals have brought a keen interest to bear on them. These areas most notably include psychometrics, psychophysiology, signal analysis, neuropedagogy, and embodied cognition.

Rad Siddo is providing the lab with expertise in the area of psychometrics, with a special focus on mathematics anxiety. He has implemented a number of instruments on the web that link with

Academic Computing Services' secure questionnaire system. Psychometrics is particularly crucial in helping to analyze, classify, and interpret brain behavior from different groups of participants. Psychometrics is a branch of psychology that deals with the design of an instrument, administration of the experiment, and interpretation of quantitative data for measuring, identifying, and classifying various psychological aspects of learners' knowledge, abilities, skills, and personality traits.

In lay terms, a psychometric instrument, also known as the survey, collects data on various topics. Writing thoughtful, well-conceived questions and administering them in a standardized fashion ensures the validity and reliability of the instrument and the accuracy of the data,which will facilitate an efficient analysis and generalization of the findings. Psychometrics provides guidance to interpreting psychophysiological data.

Shoaleh Bigdeli is providing the lab with expertise in psychophysiology. She brings her previous nursing experience with psychophysiological equipment, along with a deep caring and concern for the well being of participants to our research efforts. Shoaleh's area of interest involves using psychophysiological methods, such as EEG, heart rate, skin conductance, and so forth, to bear on the study anxieties associated with English as a Second Language (ESL) acquisition, particularly amongst Iranian women.

Anxiety, as a negative emotion, is a state of uneasiness and apprehension. It is a state of intense, often disabling apprehension, uncertainty, and fear. Anxiety results in deficient inductive reasoning, slowed decision latencies, shallow depth processing, reduced memory span-impaired attention control, and diminished performance (Gower, 2004). Combined with psychometrics, embodied responses such as these are particularly conducive to study using the equipment and facilities in the lab (Campbell, Siddo, and Bigdeli, 2007, April).

Rad and Shoaleh have also been assisting me in preparing demographic and prescreening questionnaires for our participants, as part of our informed consent process for Research Ethics Board approvals. Working with eye-tracking and psychophysiology equipment is classified as minimal risk, in that the former technology involves some exposure to very low levels of infrared light, and the latter may involve exposure to very low levels of isolated electrical current.

One of the most technically demanding components of the lab's activities concerns the analysis of EEG signals. The thinking brain generates an electromagnetic field, which produces fluctuating voltage potentials on the scalp, which in turn can be detected and measured with EEG electrodes and amplifiers.

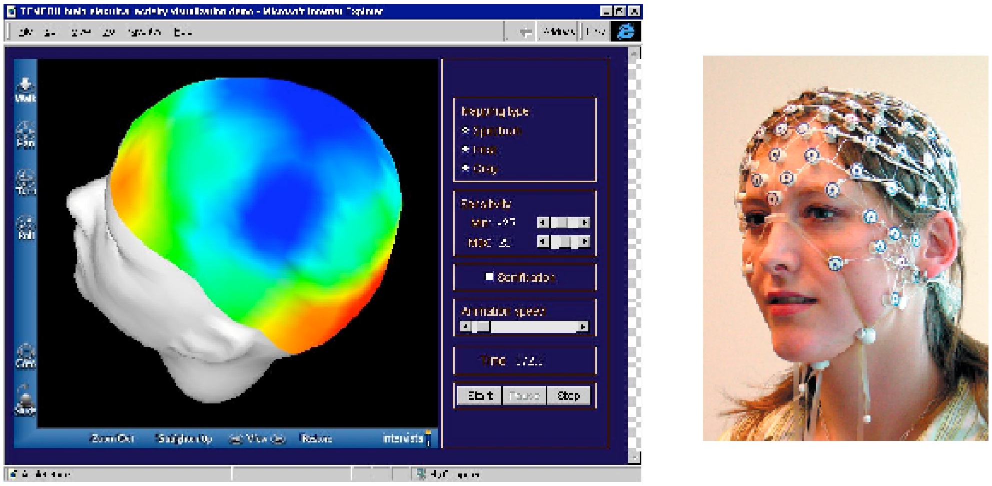

Fig. 3: Voltage potentials measured by EEG

These measurements can be taken thousands of times a second from each electrode, generating very large waveform data sets. These waveforms can then be analyzed using signal-processing methods, such as fast Fourier Transforms (FFT) and wavelet analyses, to determine, amongst other things, their frequency content.

In astronomy, the spectrograph enabled the astrophysical measurements and analyses of starlight in terms of frequency content, leading to great cosmological insights, such as the red shift phenomenon. Similarly, in psychology, the analysis of brain waves from EEG is providing significant insights in psychophysiology and psychophysics. As a case in point, consider the insight or "aha" phenomenon itself. Jung-Beeman and colleagues (2004) have found that reports of insight are preceded by an increase in power in the 30 to 50 Hz “gamma” ranges around the right temple region.

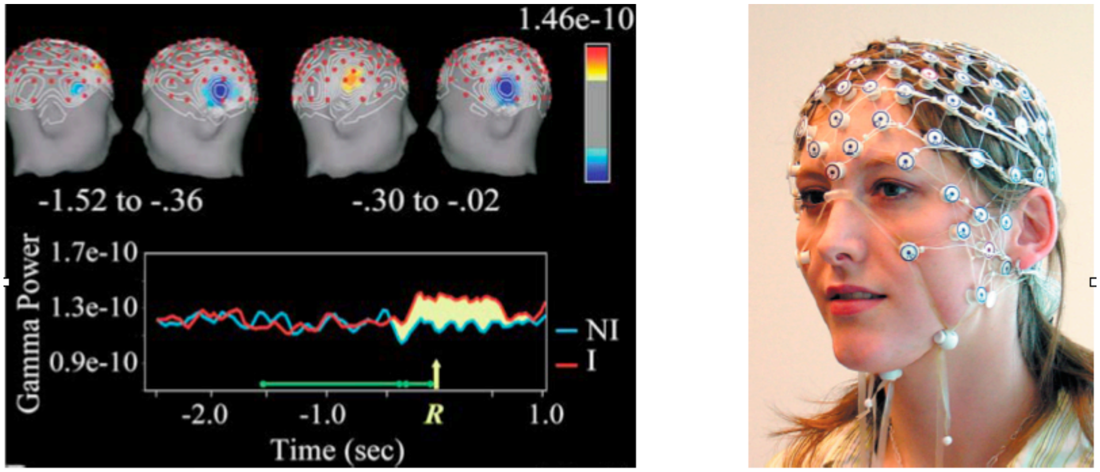

Fig. 4: EEG Insight Effect, after Jung-Beeman, et al. (2004)

With regard to the data set illustrated in Movie 1, we are currently analyzing the EEG data associated with that data set for indications of the insight effect reported by Jung-Beeman, et al.

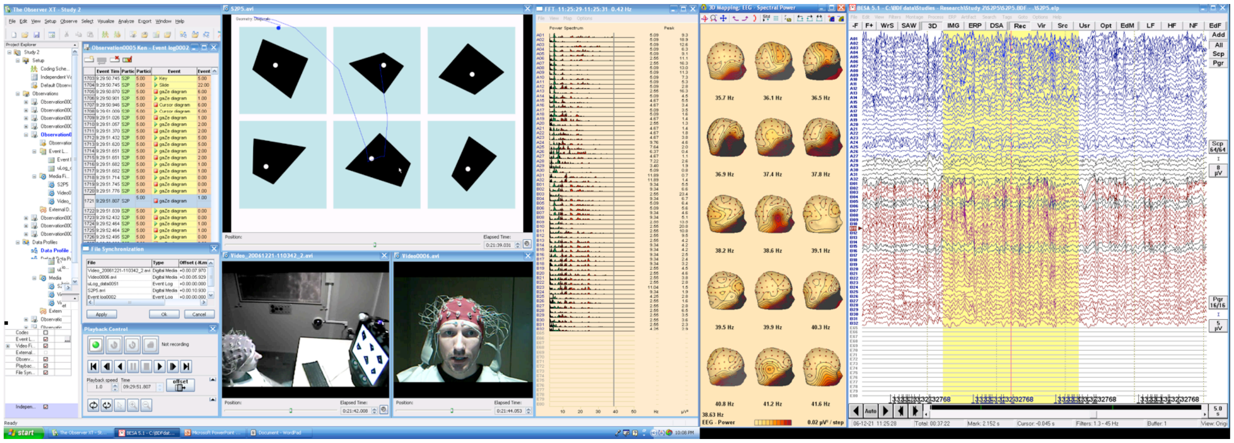

Fig. 5: In search of the EEG Insight Effect, after Campbell, et al. (Submitted)

Olga Shipulina has recently begun working with me to identify and remove muscle movement artifacts, such as from eye-blinking, which interfere with brain wave measurements, and to analyze brain behaviors indicative of correlates to such phenomena as the insight effect, along with various others that may substantiate, refine, or refute traditional behavioral-based educational models of cognition and learning. Characteristic signatures of body and brain behavior associated with cognition and learning constitute fundamental entailments of the embodied paradigm. Kerry Handscomb is working with me to further develop these entailments, specifically with applications toward geometrical perception and reasoning. Understanding the dynamics of embodied cognition is crucial to reliably identifying mind-body correlates that are bound to become stock and trade in educational neuroscience (Campbell & Handscomb, 2007, April). Once such signatures have been reliably established, and we have a better idea of what we are looking for, I anticipate extending these psychophysiological methods beyond the lab into more (electromagnetically) noisy environments.

It is one thing to identify mind-body correlates of cognition and learning, but how to apply that knowledge is another. Toward that end, we have been placing much attention on how to present stimuli and engage learners in ways most conducive to the methods we seek to employ. Phil Winne's learning kits and associated gStudy technologies provide a promising venue in this regard (Campbell, 2007, April). Further in this regard, Ken MacAllister has been serving well as a liaison between my lab and Phil's lab. Two masters students, one in Cognitive Psychology and the other in Educational Technology have recently begun working with me in collaboration with David Kaufman's SAGE project, investigating a self-awareness game that is played using biofeedback.

The ENGRAMMETRON is more than an educational neuroscience laboratory; it is an incubator for researchers and practitioners to reciprocally share ideas, knowledge, and information about the embodied mind and activities of teachers and learners. Addressing matters of affect and mentation, as manifest in somatic and brain behavior, the ENGRAMMETRON enables study of experiences and behaviors of learning, and to ultimately provide a practical research-based theory of neuropedagogy that goes well beyond the often vague, speculative, and misconceived notions of "brain-based learning."

Complementary to her role as the lab's outreach coordinator, Kate Patten is laying important groundwork for neuropedagogy as part of her doctoral thesis. She is developing what she refers to as a somatic appraisal model of emotion (Patten, 2007, April). In so doing, Kate is building a case for her doctoral thesis that would see matters of affect placed front and center; i.e., primary to matters of cognition, with regard to curriculum and implementation.

There are countless other possibilities and potentials to be realized for educational neuroscience in addition to my primary interests in using computer enhanced learning environments to identify mind-body correlates of mathematical cognition, problem solving, and learning, for the sake of improving mathematics teacher education. To mention just a few, in no particular order:

- Assessing and improving human-computer interfacing and instructional design for computer enhanced learning environments
- Investigating metacognitive factors associated with studying, re-study, learning communities, and tele-mentoring
- Investigating the potential of neurofeedback in alleviating anxieties and improving attention, reasoning, and recall
- Determining the role of sleep and the influence of fatigue on performance
- Extending and applying methods and results of educational neuroscience to classroom contexts

This coarse-grained list can be and is currently being broken down into experimental designs of much finer granularity. Many more people are required to become involved to bring educational neuroscience into full fruition. Toward this end, I have been offering a special topics graduate level course entitled Educational Neuroscience: Background, Theories, and Methods. This course was offered for the first time in the Spring semester of 2006, and is running again in Spring 2007. Six students from the first offering are currently working in or remain associated with the lab. Many of the students in this year's offering are designing experiments to run in the lab as a means toward fulfilling a course project requirement. Other faculty colleagues have collaborated in writing three applications for funding that, if granted, would involve running experiments in the

ENGRAMMETRON. Moreover, two different industrial ENGRAM/ME partners have offered exclusive royalty free access to advanced signal and image processing software for use in analyzing ENGRAMMETRON data sets.

CONCLUDING REMARKS

What might we anticipate from educational neuroscience, looking more deeply into the future? In a more speculative sense, imagine being able to better assess how well learners have learned, and being able to augment learning using neurofeedback and other cybernetic devices. Imagine the possibilities of being able to identify brain states that are most conducive to various aspects of learning, such as memorizing, recall, concentrating or focusing, critical mindedness, and other forms of reasoning. Imagine, further, developing pedagogies for enabling and empowering learners to more readily recognize and enter such states of mind at will. Imagine being able to better remember one's dreams, and to use them more constructively and deliberately as an incubator for planning and problem solving. Educational neuroscience is just being born, and who knows what the future will hold. Be that as it may, the ENGRAMMETRON has been conceived, designed, and developed to serve both as a cradle and a home base for educational neuroscience.

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