Paper Title Connecting Levels of Analysis in Educational Neuroscience

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Connecting Levels of Analysis in Educational Neuroscience

In this paper a multi-level theoretical and methodological framework for educational neuroscience is presented. The framework incorporates levels of explanation and methodologies both from education and brain sciences. The purpose is to initiate a discussion on the major goals of educational neuroscience as a field, discuss which approaches can provide the ground for a fruitful transdisciplinary fusion of ideas and methods from relevant fields, and propose embodied approaches to cognition as a theoretical scaffold that can amalgamate the multiple levels of inquiry.

After Marr's influential work on distinct levels of analysis (Marr, 1982) for information processing systems it became common wisdom to approach cognition as a complex system that has multiples levels of organization (McClamrock, 1991). Marr introduced three levels, computational, algorithmic and implementation, to avoid study of information processing being reduced to only a single level. We propose that the idea of approaching to cognition as a complex system that should be studied in distinct but interrelated levels is applicable to educational neuroscience and discuss what levels of inquiry we should consider[1] to avoid reducing learning into a neural level phenomenon. We also argue that embodied/grounded/enactive approaches to cognition can guide us in interrelating these distinct levels and provide a shared language and theoretical ground for researchers from various fields, who contribute to efforts in educational neuroscience.

Educational neuroscience is often characterized as a bridge between neuroscience and education (Ansari & Coch, 2006). This metaphor implies that educational neuroscience is a space where researchers and practitioners from two fields interact, but not a field with its own vision, community of researchers, big questions, theoretical frameworks, and methodologies. Alternatively, educational neuroscience can be characterized as a new field that fills the gap between brain sciences and education (Campbell, 2006). This metaphor implies a burgeoning, transdisciplinary field, in close contact with other relevant fields, but with its own big questions, theories, methodologies and community of researchers. In it's current state, the bridge metaphor better characterizes educational neuroscience. However, the fast-paced progression of the field poses a future vision that better matches with the "filling the gap" metaphor. Before this happens big questions for the field, theoretical paradigms, and methodologies needs to emerge. One of the steps to be taken

There are two main characteristics of educational neuroscience that distinguish it from other fields of brain sciences. First, the purpose of educational neuroscience is not only to understand the brain mechanisms that underlie learning and cognition, but also to study how learning happens in authentic, socio-cultural contexts and to design learning interventions and learning environments based on what we know about learning. This requires incorporation of research paradigms from different fields of education and brain sciences.

Secondly, even though the name "educational neuroscience" implies an emphasis on neural level investigations, educational neuroscience should be characterized as a transdisciplinary field that incorporates multiple methodologies and levels of explanation

1 As a side note, Marr's approach was inherently computational and we do not argue for a computational approach here.

from both educational and brain science research. The main goal shouldn't be to push for neural level explanations or neuroscience methodologies as alternatives to established paradigms in education. Instead, the goal is to explore how existing paradigms of educational research can be complemented with paradigms in brain sciences to provide more comprehensive, multi-level explanations for how learning occurs. These diverse levels of explanation, i.e., socio-cultural, first-person, behavioral, cognitive, evolutionary, neural, physiological, and genetic, are grounded in different research traditions, some of them in education, others in cognitive science / brain sciences. Educational neuroscience faces the challenge of theoretically connecting these levels to provide coherent multi-level explanations for learning. We formulate the main challenge in current state of things as to connect these levels and provide explanations that informs both mechanisms of learning and cognition as well as learning design, and educational practice and policy. One difficulty here is the lack of a shared lingua across people from different fields and paradigms. There is a need for a theoretical framework that is operationalized across all these levels that can act as the basin that can bring together these levels. Embodied/grounded/enactive (Barsalou, 2008; Clark, 1999; Froese & Ziemke, 2009), situated (Brown, Collins, & Duguid, 1989), ecological (Gibson, 1979) and dynamic systems (Beer, 2000) approaches have roots in philosophy, psychology, neuroscience, anthropology, robotics/AI, education, and linguistics. The inherently multi-level, transdisciplinary nature of theories of embodiment and situatedness presents a unique match with the trends and current orientation of educational neuroscience as a field.

Multiple Levels & Diverse Methodologies

Filling the gap between education and brain sciences, educational neuroscience concerns levels of explanation and inquiry from both domains. In Fig. 1 a characterization of these levels are presented, from socio-cultural to genetic. Each level of explanation feeds from a different set of fields. For example socio-cultural theories of learning are abound in education, where the neural and cognitive level explanations dominate cognitive neuroscience. Here we present a short description of each level proposed as part of the multi-level framework. The full paper delves deeper into the methods, paradigms, theoretical approaches and the scientific communities structured around each level.

Socio-cultural level

At the sociocultural level learning is defined as a situated activity taking place in a socio-cultural context (Brown et al., 1989). At this level research on learning is conducted using design-based (Barab & Squire, 2004) , and a wide range of other qualitative methodologies. According to situated theories learning occurs as a result of situated activity in authentic contexts. This is the most ecologically valid level of inquiry. Socio-cultural approaches are very strong in education, especially in learning sciences.

First-person level

The inquiries concerns the direct experience of learners reported by the learners themselves. It is closely related to the phenomenological tradition (e.g., Merleau-Ponty, 1962). This is a level commonly ignored by psychological and brain sciences, unlike education, where the learners' first-person experiences is one of the main objects of study. Interviews, think-aloud activities, journals are some of the commonly used methods to study first-person experience. There are also some non-mainstream approaches in brain sciences that explore how first-person experience can guide neural-level investigations (e.g., Thompson, Lutz, & Cosmelli, 2005; Varela, 1996)

Behavioral level

Behavioral studies focus on measuring learning and studying cognitive processes through observable behavioral indicators (e.g., reaction time, accuracy). There is a established tradition of behavioral science in psychology. Cognitive models are often assessed based on their ability to predict and model human behavioral performance. Behavioral data also accompanies and guides analysis of neuroimaging data in cognitive neuroscience studies.

Cognitive level

Cognitive level involves study of mental processes (e.g., memory, attention, perception). An important focus at this level is developing mathematical / computational models of cognition and learning. Based on an information processing approach (Shiffrin & Schneider, 1977), cognition is characterized as processing inputs (perception) to produce outputs (action), instead of simply responding to stimuli (behaviorism). Cognitivisim distinguishes between perception and action, as well as emotion and cognition (in embodied approaches these distinction are vague). The cognitivist paradigm is strong in psychology and most cognitive neuroscience research targets unfolding the neural correlates (Marr's 3rd level) of the processes covered in the cognitive level (Marr's 1st and 2nd levels).

Neural level

Perhaps, neural level explanations are the ones most emphasized in discussions about educational neuroscience. With fast-paced developments on neuroimaging technologies since 1990s neural level investigations are pioneering psychological and brain sciences (Dolan, 2008). A wide range of methodologies is available to researchers (e.g., fMRI, EEG/ERP, MEG, fNIR). One shortcoming is the lack of ecological validity of most studies conducted at the neural level. Because there are a wide range of constraints limiting the activities participants can engage with, cognitive neuroscience investigations often can't use authentic tasks or take place in authentic environments. This is currently a major challenge for educational neuroscience. However there is a growing body of literature reporting results and new methods that aim at conducting ecologically valid neural level investigations (see Kivikangas et al., 2011; Ninaus & Kober, 2014).

Physiological level

The physiological level refers to biological processes that are not considered a direct part of the neural processing system. These include measures like heart rate, cortisol level, and, electrodermal response (galvanic skin response). These measures are good indirect measures of the mental and emotional state of the participants in certain task conditions. They are often used in psychology and, especially in affective, neuroscience studies. Physiological measures are promising in studying student motivation and affect during learning in authentic contexts.

Evolutionary level

Evolutionary explanations for human cognitive abilities often help make connections among different cognitive faculties that wouldn't be possible otherwise. Studies at this level either concern research on historical evidence on how human cognitive abilities evolved or comparative studies with animals. Embodied approaches to cognition are closely linked with evolutionary psychology. One of the main premises in embodied cognition is that the bodily systems originally evolved for other functions were redeployed for more conceptual/abstract thinking (Anderson, 2007). Evolutionary approaches are widely used in psychology but not as much in education.

Genetic level

Genetic level concerns how genetic patterns interact with learning processes and performance. Research at this level mainly focuses on understanding cognitive and behavioral disorders, how genetic dispositions affect learning and how we can develop preventative or compensatory interventions (e.g., Schulte-Körne et al., 2007).

Conclusion

In an ideal world we would be able to conduct both ecologically valid and reproducible studies and develop theories of learning encompassing all the levels provided. In a less ideal world our investigations and theories incorporate at least some of these levels. However most research explicitly focus on how learning occurs at a given level. One reason for this is the methodological difficulty of collecting data at each level and analyze to develop a theory that relates all these levels. For example ERP research requires collecting many trials of data for the same condition to reliably study the effect of a manipulation on a specific component (Luck, 2005). In addition EEG/ERP data collection requires subjects to be relatively steady, and even limit control the most natural actions like eye-blinking, or head movements. These constraints make it very hard to design authentic tasks that could improve ecological validity. In addition the lab environment is artificial and does not provide an authentic socio-cultural context. There are attempts to overcome these challenges, for example by exploring methodologies that would allow single-stimulus EEG/ERP experiments (e.g., video games), and mobile EEG devices that can allow data collection in authentic environments, like classrooms. There are also some efforts in relating subjects first-person experience with behavioral and neural data (e.g., neurophenomenology). These are burgeoning efforts that are yet to mature and perhaps will become mainstream research methodologies.

Both the authenticity of the, socio-cultural, context as well as learners' first-person experiences are typically highly prioritized in educational research. In brain sciences notions like reproducibility of empirical investigations, reliability and validity, and power of statistical results are important. These priorities reflect different epistemological assumptions and values systems. Educational neuroscience is in need of finding a meeting ground that can accommodate (with some compromises) these different levels. In the current state of things educational neuroscience sometimes acts as a platform, where brain scientists share what they know about the brain and cognition with educators and discuss implications. This was previously called the "one-way model". The desirable mode of interaction is one where there is a two-way communication.

The multi-level perspective empowers educators and acknowledges the fact that educational neuroscience is not a colonization of the educational landscape by brain science knowledge and methodologies, but rather two fields coming together to yield to the emergence of a new field, situated in between, where perspectives, methodologies and levels of explanation from both originating fields are valued and used.

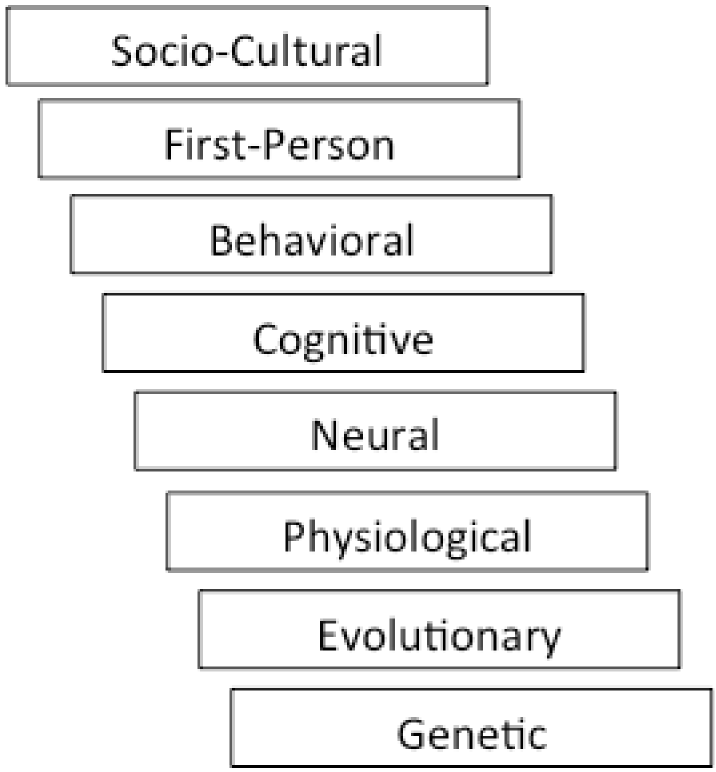

Figure 1. Levels of analysis for educational neuroscience.

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