Editorial: Articulating theory, data, and implications in educational neuroscience

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Introduction

Learning can be conceived of as a sequence of events (Anderson, 2002). In this view, process-oriented examinations of learning are warranted and increasingly used. In continuity with this approach, trace methodologies focusing on how events unfold over time supplement behavioral data sources with psychophysiological data sources. Behavioral data sources include think-aloud, performances, eye-tracking, facial muscular configuration, etc. Psychophysiological data sources, as used in recent laboratories, include high-density electroencephalography (EEG), electrocardiography (EKG), electrodermal activity (EDA), pupil size, body temperature, and respiration.

While various theories provide clear indication that all these behavioral and psychophysiological processes are responsible for learning and thus can explain learning in computational terms, extant theory relating these behavioral and psychophysiological processes is scarce, especially in light of the needs associated with linking educational research and applied outcomes with such methodologies.

What would be required is affective and cognitive neuroscience explanations of all constructs related to learning, as determined by current educational research. These explanations would bridge, computationally, psychophysiological and cognitive/affective functioning over timescales. In order to fulfil the needs of educational research, the most pressing thing is to tackle the daunting task of linking psychophysiological functioning with behavior over extended periods of time. Two general approaches can be used in a complementary manner in this endeavour: the first one is to conduct theory-driven process-oriented analyses of multi-channel measures of learning processes and the second one is to formulate data-driven inferences of learning processes through process-oriented psychophysiological and behavioral measures.

Theory-driven process-oriented analyses of multi-channel measures of learning processes

According to Castelfranchi (2014) and Newell (1990), a complete model of cognition has to specify the cognitive mechanisms producing and governing (controlling) behavior as well as its neural and body implementation. We should know how and why brain structures are associated with brain micro-mechanisms and emergent cognitive processes, including inter-individual functioning, and eventually including an evolutional (biological, developmental, and historical) perspective. While cognitive psychology has been fertile in suggesting models of cognition, cognitive neuroscience cannot provide at this time (a) complete interfacing mechanism(s) between psychophysiological functioning and cognition as observed and explained in behavioral terms. This is needed to ground an educational neuroscience perspective towards possible contributions to educational research. The translational research process involves bidirectional relations between two bridges across three disciplines respectively representing the psychophysiological implementation, the target phenomenon (learning), and a field of application: cognitive neuroscience, cognitive psychology, and education.

Data-driven inferences of learning processes through process-oriented psychophysiological and behavioral measures

Because cognitive science (cognitive and affective neuroscience, as well as psychology) cannot always provide theory required for the interpretation of process-oriented data, it is necessary to search for other sources of constraints in the interpretation of empirical results that can further our understanding of learning and its determinants across multiple levels in the cognitive architecture. Current literature that can support the data-driven inference of learning processes on the basis of process-oriented, multi-channel recordings of behavioral and psychophysiological data suggests that a focus on the temporal aspect of the data can be productive. Specifically, it seems promising to investigate the benefits and limits of temporally-indexing and synchronizing these multiple sources of data, so that within-channel and between-channel temporality becomes a constraint mechanism helpful in making plausible inferences of learning processes. There are two sources of dependencies in the temporal domain: causality between antecedent and consequent events, as well as a cumulative effect of micro-processes on macro-processes. The causality between antecedent and consequent events refers to the notion that an event is occurring because and only because of preceding events. The cumulative effect of micro-processes on macro-processes is the principle that a higher-order process is constituted of a determined (and presumably stable) series of faster, lower-order events.

The papers in this special issue

The papers in this special issue of Themes in Science and Technology Education capitalize in their own respective ways on the principles discussed above. Zacharis, Mikropoulos, and Kalyvioti rely on the EEG signature of psychological constructs. They report on an interesting study of cognitive processing of visual educational content, comparing the effect of real-life and digital environments on working memory and attentional demands. Real-life, 2D, and 3D scenes. In a task requiring the participants to compare two scenes to identify which object(s) were in a different position, within-subject comparisons showed that the processing of the first scene (which seems to involve identifying each object and their position and memorizing them) is more demanding in terms of working memory load and working and spatial memory than the second scene (which seems to involve locating the objects and comparing their current location with their location in the previous scene held in working memory). It seems therefore that the initial processing of a scene is more demanding than a comparison between two scenes in which a few objects have been moved. Perhaps the second finding of this study is even more intriguing: the processing of the first scenes is more demanding in terms of working memory load and working and spatial memory in the virtual environments (2D and 3D) than the real-world environment. Can this attributed to the fact that a virtual environment is a reduction of a real-life environment, in the sense that all properties of real-world objects are not fully modeled down to their most basic sensory characteristics in their virtual representations?

Patten and Campbell explain affective functioning by relating explanations at multiple levels (including physiological, psychophysiological, and psychological levels). They describe a pilot study aiming to determine if a program designed to teach parents about affect and affect regulation strategies is associated with their self-reported gains in knowledge about affect and emotion regulation practices with their children. While the results are encouraging but very preliminary at this time, the theoretical model underlying the program they developed offers very interesting insights regarding the phenomenological and functional aspects of affect, the benefits of emotion regulation, and the prescriptions for parents and their children. In particular, the distinction between dispositions or moods, basic emotions, and feelings was necessary to define the target of emotion regulation. In addition, the description of the nature, development and function of emotion regulation helps in formulating adequate parenting practices in emotion regulation. Finally, the theory reviewed and the model created converge in a 12-hour training program for parents that should now be tested with experimental designs with samples of parents and their children.

Mercier and Bédard describe a very general view of an emerging research topic in educational neuroscience involving psychophysiological, psychological, and interpersonal levels of explanation. They make the case for the use of electrophysiological measures in complement to behavioral measures in the study of tutoring that is likely to involve the interplay between theory-driven and data-driven analytic strategies. Hinging on the notion of contingency (the moment-by-moment correspondence between the help provided by a tutor and the tutee's learning needs) as the main explanation for the efficacy of tutoring as a teaching method, they suggest that what can be observed and used by the tutor and the tutee in a tutorial interaction is limited. In a view of tutoring stressing the involvement of the tutor and tutee in the monitoring and regulation of everything that is done in a tutoring interaction, electrophysiological measures interpreted through cognitive and affective neuroscience theories can provide pertinent information during or after a learning interaction. In principle, if electrophysiological data can be collected and interpreted appropriately in conjunction with other data, this information can be used productively by students and tutors. If this view seems plausible from a theoretical and methodological point of view, empirical studies are needed to establish its potential benefits in applied situations.

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