# Towards Group Cognitive Analysis of Collaborative Learning with Eye-Tracking and Brain Imaging Technologies

Murat Perit Çakır, METU Informatics Institute, Department of Cognitive Science, Ankara, Turkey
perit@metu.edu.tr

**Abstract:** This paper aims to motivate the need for a group cognitive approach for the multimodal analysis of learning to better account for neural and ocular correlates of collaborative learning. In reference to related work in the emerging fields of two-person neuroscience and dual-eye tracking, the paper argues for the need for moving from a single-mind perspective to a group cognitive perspective where neural and ocular correlates of joint meaning making are investigated in the context of sequentially unfolding social interaction.

Learning spans a continuum across individual and social scales. At the individual level, learning encompasses cognitive and behavioral changes exhibited by an individual as well as neurobiological changes triggered within an organism. At the social level, learning is encapsulated in the dynamics of interaction among collectivities, and embodied in the practices and knowledge artifacts of a community. Such levels of analysis have been of interest to multiple disciplines including cognitive neuroscience, cognitive science, learning sciences, psychology, sociolinguistics and cultural anthropology. However, differences among the conceptual frameworks employed by these disciplines make connecting levels of analysis a challenging task.

CSCL is a growing discipline within learning sciences that treats learning as a fundamentally social phenomenon. A distinctive aspect of the CSCL community is its collective interest in designing and analyzing technologies for supporting learning at both small group and communal levels. Therefore, CSCL environments are perspicuous settings to capture and analyze learning interactions at multiple temporal and social scales (Dyke et al., 2011). The discussions for connecting levels of analysis in CSCL naturally revolve around how one can coordinate findings across the individual, small group and community levels. One particular proposal in that regard involves focusing on the small group unit of analysis as a mediator between individual and communal levels of analysis, which requires close attention to the social mechanisms through which participants organize their interaction by coordinating bodily, representational and linguistic resources (Stahl, 2010).

Recent advances in technology have led to the development of more portable and affordable brain imaging and eye tracking tools, which offer new opportunities to observe the coordination among brain and eye-gaze activity of dyads during joint action. However, with the exception of a few cases, both eye tracking and neuro-imaging studies have traditionally focused on the individual unit of analysis, which often makes it challenging to make sense of the neural and ocular patterns observed during learning experiments. This paper provides a brief overview of some of the key findings of such studies to illustrate how learning related phenomena is studied with the help of these modalities. Then, based on a discussion of some of the limitations of the individualistic approach, the paper argues for the need to move from a single-mind perspective to a group cognitive perspective to better capture and make sense of ocular and neural correlates of learning.

Existing brain imaging methods allow the monitoring of the human brain through changes in electrical potentials (EEG), magnetic fields (MEG) and cerebral blood oxygenation (fMRI, PET, DTI, fNIRS) induced by neural activity. Each imaging modality has pros and cons in terms of the temporal and spatial resolution of the images obtained, the need for invasive interventions, sources of artifacts that hinder the detection of cognitive effects, portability, equipment cost and ecological validity of the circumstances where the images can be obtained. Due to such factors, neuro-imaging modalities have been predominantly deployed in controlled experimental settings to investigate neural correlates of learning at the individual level (Haier et al., 2009). Such studies typically involve longitudinal designs where improved behavioral performance is correlated with functional and anatomical changes observed in the individual's brain. The results point out that the human brain is extremely good at adapting itself in response to cognitive demands originated from the task environment by utilizing its neural resources in an increasingly efficient way as a consequence of learning. Despite individual differences, cortical areas that respond to specific cognitive processes are distributed in a fairly uniform way. In addition to areas that selectively respond to specific kinds of cognitive processes, some brain regions can be shared among multiple types of cognitive tasks. Such empirical insights allow us to develop better theories regarding the functional organization of the brain and the nature of the cognitive processes realized by it.

Individual level analysis in controlled labs has contributed to our understanding of the functional organization of the brain as well as the nature and the limits of its plasticity in important ways. However, some of the most important influences that the brain adapts itself to are of socio-cultural nature, which are systematically eliminated in the lab setting. For instance, acquiring a language and engaging with other individuals fundamentally shape not only the way we think and act in the world, but also the functional organization of the brain (Dehaene, 2009). Such factors have motivated the need for moving beyond the individual unit of analysis in cognitive neuroscience. Hasson et al.'s (2012) fMRI study on brain-to-brain coupling exemplifies this recent analytical shift in the field, where they compared asynchronous scans of a speaker telling an unscripted story and speakers listening to the same story. Hasson et al. found that even though dyads were not engaged in simultaneous conversation, the speaker's and the listeners' brain activities at their language centers got in synch when the listener genuinely followed what had been said in the recorded speech. Recent work employed simultaneous scans of two interlocutors with portable imaging tools such as EEG (Dumas et al., 2012) and fNIRS (Cui et al., 2012), where increasing levels of neural coupling were observed at pre-motor and pre-frontal areas during collaborative tasks such as imitating hand gestures and finger tapping rhythms. Coupling measures such as Granger causality, wavelet coherence and Kuramoto's synchronization model of complex oscillators are used to detect the strength and the temporal course of coupling among dyads induced by collaborative action, albeit in relatively simple tasks due to analytic challenges.

Similar to most brain imaging studies, eye-tracking research has also considered the individual as the primary unit of analysis. In the context of learning sciences, multimedia learning has been one of the most important applications of eye-tracking research. Such studies often control for the content and the pace of instructional materials, measure eye fixations to identify what parts of the interface learners allocate their attention to, and finally relate these measures to learning outcomes to identify which presentation strategies work better. Since fixation sequences by themselves do not reveal what subjects are thinking or whether they are really paying attention, think-aloud protocols are often employed to interpret the fixation sequences. However, learning to see relevant visual structures at a scene and to associate them with appropriate terminology are also socially shaped processes (Goodwin, 1994), so think-aloud alone is not sufficient to study the relation between learning and eye-fixations. Therefore, a similar argument for switching to the small group unit of analysis can be made for the eye-tracking paradigm as well. The decreasing cost of desktop and mobile eye-trackers have made it practical to track the eye gaze of multiple subjects simultaneously while they are collaborating on a shared task (Nussli & Jermann, 2012). The degree of cross-recurrence among fixation sequences of interlocutors provides researchers useful information regarding to what extent the participants can mutually orient to each other and to the objects in their shared scene.

The review of recent studies in brain imaging and eye tracking research indicate that there is an increasing interest in transcending the individual unit of analysis in an effort to better make sense of neural and ocular correlates of learning. Existing studies that employ the dual brain imaging and eye tracking paradigms focus on devising quantitative metrics that reveal the degree of coupling among dyads to predict the quality or effectiveness of collaboration, without necessarily focusing on the micro-level details of the sequential organization of actions/utterances through which dyads achieve joint attention, coordinated action and shared understanding. Employing a group cognitive perspective is necessary to build a unified account of the interrelationships among the socio-cultural, ocular and neural aspects of collaborative learning. Because the participants naturally articulate their reasoning and respond to each other in collaborative settings, small group level of analysis provides a perspicuous setting to investigate the relationship between what participants do together, where they allocate their attention and how their brains respond to the socio-cultural influences. On the one hand, by focusing on the organization of the interaction, one can better make sense of how brain-to-brain coupling is modulated while peers coordinate their actions to achieve shared understanding. On the other hand, insights obtained from eye-tracking and neuro-imaging modalities can shed further light into how collaborative learning shapes an individual's cognitive processes.

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