Chapter 9
Eye-Tracking the Emergence of Attentional Anchors in a Mathematics Learning Tablet Activity

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ABSTRACT

Little is known about micro-processes by which sensorimotor interaction gives rise to conceptual development. Per embodiment theory, these micro-processes are mediated by dynamical attentional structures. Accordingly this study investigated eye-gaze behaviors during engagement in solving tablet-based bimanual manipulation tasks designed to foster proportional reasoning. Seventy-six elementary- and vocational-school students (9-15 yo) participated in individual task-based clinical interviews. Data gathered included action-logging, eye-tracking, and videography. Analyses revealed the emergence of stable eye-path gaze patterns contemporaneous with first enactments of effective manipulation and prior to verbal articulations of manipulation strategies. Characteristic gaze patterns included consistent or recurring attention to screen locations that bore non-salient stimuli or no stimuli at all yet bore invariant geometric relations to dynamical salient features. Arguably, this research validates empirically hypothetical constructs from constructivism, particularly reflective abstraction.

DOI: 10.4018/978-1-5225-1005-5.ch009

INTRODUCTION

Eye-tracking is a technique for collecting data in the context of conducting empirical studies of human perception, cognition, and behavior. As its name suggests, eye-tracking is a means of determining aspects of participants' sensory perception in the visual modality—where they are looking. In turn, locations of visual perception can be used to infer foci and patterns of gaze as these are relevant to making sense of human cognition and behavior. Over the years, eye-tracking hardware has advanced to the point that the instruments are now mobile, so that gaze data can be collected not only in research laboratories but also in the field, such as in investigating the perceptual behavior of supermarket consumers.

Although eye-tracking technology has been used quite widely in cognitive psychology for many decades now, it has only quite recently been employed in the context of conducting educational research. In particular, eye tracking has been used to study how students solve problems in the domains of physics and mathematics (Hegarty & Just, 1993; Hegarty, Mayer, & Green, 1992; Landy, Jones & Goldstone, 2008; Suppes, 1990), reading and comprehension (Paulson & Henry, 2002; Rayner, Chace, Slattery & Ashby, 2006), and multimedia learning and interaction (van Gog & Jarodzka, 2013; van Gog & Scheiter, 2010). The particular contribution of eye-tracking to educational research has been by combining it with data of students' physical movements and verbal utterances. Knowing where and possibly what students are looking at as they interact in a designed environment has enhanced micro-level analyses of learning to a level that had not been possible without this multi-modal approach.

The purpose of this chapter is to show an application of eye-tracking in studying students' learning of mathematics with a tablet application. As will be revealed, a proposed novelty of the chapter is that the objects that students gazed at often were not really there, in the sense that there were not objective stimuli on the tablet interface that could account for the students' perceptual behavior. To be clear, we do not simply mean that these objects were virtual, rather, they were invented by the students as figments of their own active imagination: imaginary gestalts or assemblages that the students created spontaneously in their attempts to solve an interactive manipulation problem presented on the screen. Moreover, our data suggests that as these objects were created, the students began using information about these objects to facilitate their motor activity. At times the students would manipulate these objects, referring to them in speech and gesture as if they were actually there.

As educational researchers, these imaginary objects are important to us, because we interpret them as revealing of cognitive mechanisms at play when situated sensorimotor activity evolves into generalized conceptual understanding. In particular, we believe that these present–absent objects that our study participants are building in their mind's eye are vital for developing mathematical concepts. We submit that these figments are evidence of a goal-oriented coordination between the sensory input and the body; what cognitive-developmental psychologists call sensorimotor schemes. That is, eye-tracking appears to give us windows onto students' mental constructions. It could be that we are offering the field first glimpses into a form of human behavior that is fundamental to Jean Piaget's theory of genetic epistemology known as constructivism (Abrahamson, Shayan, Bakker, & Van der Schaaf, 2016).

Our research is situated within a larger program investigating the nature, emergence, and cultivation of embodied mathematical cognition (see next section). The particular mathematical topic targeted by our materials and activities is that of proportional relations, and more specifically student development of deep understanding for the meanings inherent in a symbolic form such as "2:3 = 4:6". We were inspired by recent ideas in psychology and educational-technology research and practice: embodied cognition. Embodied cognition refers to the idea that we think with and through our bodies (Antle, 2013; Howison,