Preface to Part X

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I write this preface fresh off of a week-long meeting and conference hosted by the Johns Hopkins University School of Education and the Dana Foundation on the topics of creativity, the arts, learning, and the brain. Last year's report on this intersection from the Dana Foundation (2008) encompassed empirical studies performed by some of the most eminent cognitive neuroscience laboratories in the country. Consequentially, there is a swell of ground support emerging from the public's increasing enthusiasm of the promise of cognitive neuroscience to inform, intervene, and enhance the experience of education. The metrics between science and education are far from one another as neuroscience methods treat the learner primarily in isolation, and a minimum requirement or expectation of the process of education is that it takes place in the social environment of the classroom. The empirical demonstration of functional plasticity related to participation in music and the arts is crystallizing a platform that may well hold the first-tier of efforts designed to problem solve in the space between isolated neuroimaging techniques and the learning and performance dynamics from education and the social environment that we are so eager to see there.

Within this context, the relationship between music and mathematics comes to mind. Savants demonstrate a special affinity for information in these domains (Kalbfleisch 2004). What is it about the nonverbal rule structures of each that renders them so transparent to such a highly atypical brain that yields such a highly atypical mind? The power of mathematics lies equally in processes of numeracy and geometric abstraction. Neuroscience has more deeply explored aspects of the first. How the brain perceives, processes, and generates nonverbal information and abstraction will lay the path between mathematical processes and their applications in engineering, design, and the arts. How does one begin to articulate beyond a heuristic level a well controlled but complex enough experimental paradigm or model that will potentially isolate functional neural systems which make the transformative difference during mathematical learning? If Weisberg (1986, 1993) and Ward (2007) are correct in that creativity makes fantastic use of rudimentary processes, what accounts for the transformation? Embedded in this notion, mathematics has both sequential and non-linear properties. Thus, the challenge to untie the creative

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process also bears on the understanding of mathematics, how one learns, and in characterizing and supporting those individuals who have intuitive affinity for it.

The educational psychology theory, constructivism (Vygotsky 1928; Bruner 1960; Piaget 1970, 1980), coupled with information from cellular and cognitive neuroscience that defend it as a neurobiological substrate of learning, situates this challenge in a constituent net of potentially fruitful ideas. Though there is a range of entry point definitions (Phillips 2006), in general, constructivism purports that all meaningful learning (and hence, production) occurs as a function of an individual's subjective interaction and experience with his or her environment. Cross-species studies of the understanding of imitation and action (Rizzolatti and Arbib 1998; Rizzolatti and Craighero 2004), neural plasticity (Quartz and Sejnowski 1997; Alvarez and Sabatini 2007) and memory Izquierdo et al. 2006; Squire et al. 2007 suggest a case for a neurobiology of constructivism and hence, a rich intellectual space for the means of conceptualizing feasible studies of mathematical processes in neural and computational science. Constructivism articulates and encompasses the values associated with preserving the role of context in neuroscience experimental design. The issue of context has to be maintained and addressed in efforts to pinpoint neuroanatomical substrates of mathematical processing. Ideally, attempts to explore the relationship between the brain's neural systems and the cognition they generate must account for the person's own theory of mind (the ability to see oneself separately from others and to realize that others have independent agency), sense of interoception (one's sense of the physiological condition of the body), and motivational idiosyncracies (Kalbfleisch in press). The preservation of context in experimentation will afford opportunities to better examine transformation, to understand the conditions under which it happens and where in cortex.

I recently posed the notion of the central nervous system as an *endogenous heuristic* for understanding meaning making (Kalbfleisch 2008). Our biology gives us clues about how it learns and functions best. The ability to approximate underlies and potentially unifies observations of music and mathematical ability. Elizabeth Spelke's work demonstrates this basic principle (Barth et al. 2006; Spelke and Kinzler 2007). It follows that visual spatial ability underlying mathematical process is the persistence of the brain in it's early, pre-lingual state. The challenge of the emerging field of educational neuroscience will be to coordinate neuroscience experimentation in concert with and in complement to school-based learning to examine relationships between the biological underpinnings of mathematical processes and abilities we measure psychometrically and with achievement tests. Influences from constructivism and embodied cognition will be necessary to preserve ecological validity in experimental design. While difficult, the potential result will yield finer grain knowledge of sensitive periods in the brain generated alongside school environment, instruction, and achievement.

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