Studying the Role of the Executive Functions in Early STEM Learning

Background

Carey's career has been dedicated to understanding the human capacity for conceptual representations. We are the only animal that can ponder the causes and cures of global warming or pancreatic cancer, yet we share many cognitive resources with other animals. What makes possible the human conceptual repertoire? As a matter of logic, answering this question requires specifying the innate representations infants use to make sense of their world, describing them in detail, characterizing the adult state, characterizing the differences between the initial state and the final state, and then characterizing the learning mechanisms that allow the child to navigate the differences. Carey's work has addressed all of these topics, and has combined experimental studies of children, from infancy through adolescence, experimental studies of adults, cross-cultural studies, historical analysis, and animal cognition studies in order to address the question of the origin of knowledge at three different time scales (evolutionary, historical, and ontogenetic). She has documented rich conceptual representations early in infancy, but also qualitative changes between the infant's initial state and later developing explicit knowledge, including the knowledge that is the target of STEM instruction.

Documented Research

From the beginning of her career, Carey has pursued her research with an eye to its being informed by and informing research on education. Early in her career, her main theoretical focus was on distinguishing episodes of knowledge acquisition that involve true conceptual change, which involves creating representational resources that are qualitatively different from the learner's initial representations. Over her career, she has carried out several extended case studies of genuine conceptual changes—within mathematical development, the construction of representations of natural number by young preschoolers, construction of representations of rational number in elementary and middle school, and within intuitive theories, the construction of vitalist biology in the elementary school years and the construction of an intuitive theory of matter in the middle school years (these case studies are summarized in Carey, 1995 and Carey, 2009). The theoretical context for this work, which began in the 1960s, was a reinterpretation of the evidence Piaget had provided for radical stage changes in the *kinds of thinking* children of different ages are capable of. Instead, Carey argues that Piaget's phenomena are evidence for qualitative reorganizations within specific systems of representations (e.g., theories). At the same time, entirely independently, research in education was coming to grips with the fact that a fundamental problem in education, especially within the STEM sciences, is that learning the target theories require conceptual change, a claim that also required distinguishing episodes of learning involving conceptual change from episodes of learning that do not.

Three lines of work have led to Carey's current NSF funded work on the role of executive functions in early STEM learning: distinguishing conceptual change from knowledge enrichment, the finding that some populations never make the conceptual changes achieved by normally developing children by age 7, and work in collaboration with educators on the mechanisms underlying conceptual change.

Research supports, that numeracy/arithmetic content is an extremely important target of preschool experience. For example, preschool numeracy measures predict success at mastering math skills during kindergarten. Even more important, one large study found that Pre-K numeracy skills are an important predictor of success in elementary school, overall, far more than were the early literacy measures, for both STEM and non-STEM subjects. However, and the topic of my presentation, there is another important predictor of success in STEM subjects—a suite of domain general skills, the executive functions. Executive functions underlie self-control, sustained attention, effortful planning, and cognitive flexibility. Measures of preschool executive function also predict successes at mastering kindergarten math skills, measures of EF also do so, even when controlling for early numeracy knowledge. Concurrent measures of executive function predict school readiness among Pre-K students, and school success at every grade, from K-12^{th} grade, including in all STEM subjects. Furthermore, measures of executive function in preschool predict future SATs at graduation from high school.

There are many reasons good executive function contributes to learning. Self-control contributes to being able to stay on task, to control attention, and supports better social relations with teachers and other children. While not denying the importance of the executive functions to school success reasons such as these, one can argue that the executive functions are important to STEM learning because for deeper cognitive reasons as well. STEM learning requires building entirely new representational resources, and sometimes involves conceptual change. In fact, two major studies show relations between executive functions, on the one hand, and achievements in early elementary STEM subjects (one concerning math, and one concerning the vitalist biology that was my first case study of conceptual change). These studies suggest that the executive functions are important specificially for constructing new representational resources that are qualitatively different from the student's initial understanding of the subject matter at hand—this is one of the central challenges of all STEM learning.

Measures of executive function exhibit considerable stability over development, in the sense that a child who is high, relative to peers, at age 4 is likely to be high, relative to peers, at age 12 or 18. Such stability, while important, has no implications whatsoever for how malleable the executive functions are; after all, the environmental variables that contribute to individual difference in executive function at age 4 are quite likely, on average, to remain more or less constant throughout childhood. It turns out that executive function is a trainable resource, an exercisable organ, in other words.

For more Information

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References

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