Psychologists seek to unlock secrets of children's complex thinking

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Researchers say conceptual change is extremely difficult to achieve. When children become aware the world is round, for example, they must update their knowledge about the shape of the earth and also update the kinds of conclusions they can draw in light of this new information. The goal of this research is to uncover the cognitive processes that produce updated conclusions, or conceptual changes, in math and science. Credit: Thinkstock

What is it about the human mind, as opposed to those of other animals, that makes it able to comprehend and reason about complex concepts such as infinity, cancer or protons?

That is what National Science Foundation (NSF)-funded research conducted by Harvard University professors Susan Carey and Deborah

Zaitchik seeks to find out.

The two investigators are leading a new project that explores how children develop understanding of abstract concepts over time, specifically in mathematics and in science—biology, psychology and physics. Their research could prove transformative to the practice of education.

Carey and Zaitchik's project, "Executive Function and Conceptual Change," is one of 40 projects funded in the first round of an NSF initiative called INSPIRE that address extremely complicated and pressing scientific problems.

Specifically, the project aims to determine how children develop theoretical concepts of science and math and how the learning process might be modified to increase their level of understanding.

NSF's Developmental and Learning Sciences Program in its Directorate for Social, Behavioral and Economic Sciences partially funds the research. It is one item in a program portfolio that strives to understand how children learn, and what factors influence their social and thinking skills as they become productive members of society.

Past research shows children have intuitive theories about science and math before they begin formal learning. Their intuitive theories are often radically different from the theories taught in school, but through schoolwork, are transformed into standard, often abstract ideas that were previously unknown to the students.

For example, children believe the earth is flat and draw conclusions about the world based on that assumption. When they become aware the world is round, they must update their knowledge about the shape of the earth and also update the kinds of conclusions they can draw about the world in light of this new information, such as that it is impossible to fall off its edge.

This transformation involves what Carey and Zaitchik call conceptual change—a process by which a person's knowledge and beliefs are modified over time and evolve into a new conceptual system of interconnected knowledge and reasoning.

Conceptual change is extremely difficult to achieve. Studies show it requires more than gathering new facts to replace or modify old facts; it demands, in addition, sustained mental effort to integrate all related pieces of information into a coherent body of knowledge.

"The kind of knowledge we are talking about is hard to construct," says Carey, a Harvard psychologist and the project's lead principal investigator. "You just don't get it for free."

The difficulty of conceptual change is one of the reasons teaching science and math is such a challenge. It is also a reason the Research on Education and Learning program within NSF's Directorate for Education and Human Resources co-funds the project.

Carey and Zaitchik believe that if the cognitive processes needed to produce conceptual change can be identified, better understood and successfully manipulated through simple training, it might make a big difference in a student's academic success, whether that student is in kindergarten or college.

They are especially concerned with how a suite of cognitive processes called "executive function" impacts children's ability to both build new abstract knowledge and use it throughout their lifetimes.

The components of executive function under investigation by the research team include working memory, inhibitory control and set-shifting. Working memory involves the ability to actively hold information in mind, update it and mentally work with it. Inhibitory control is the ability to suppress interference, distractions and inappropriate responses, which is important for completing cognitive tasks. Set-shifting involves the ability to flexibly switch goals or modes of operation, such as recognizing that different problem-solving approaches will be more successful in different settings.

Previous research has shown that executive function is more predictive of school readiness than entry-level reading skills, entry-level math skills or IQ. In addition, executive function has been shown to play an important role throughout a person's school years, with working memory and inhibitory control independently predicting math and reading score success in every grade from preschool through high school.

Carey and Zaitchik say there is already a good deal of empirical evidence that these processes play a strong role in school children's ability to learn and express theoretical knowledge that does not require conceptual change. In this project, however, they are testing the hypothesis that executive function also underlies the ability to achieve conceptual change.

"For cognitive change, one needs to 'think outside the box,' look at things differently from the way one had been looking at them," says Adele Diamond, one of the founders of the field of developmental cognitive neuroscience and an expert on executive function. "To get to that point, it helps to be able to try out different perspectives and experiment with looking at things this way and that.

"Playing with ideas, relating things in new ways relies heavily on working memory," she says referencing one component of executive function examined in Carey's and Zaitchik's research project.

Additionally, "to think in new ways, to see things in new ways, one needs to inhibit old ways of seeing things, old habits," she notes referencing inhibitory control, which the project leaders are also examining.

Diamond is an outside project observer at the University of British Columbia in Vancouver, where she is the Tier 1 Canada Research Chair for Developmental Cognitive Neuroscience within the Psychiatry Department there.

Work by Diamond and her colleagues provides a backdrop for Carey's and Zaitchik's approach. In pioneering research, Diamond found school activities in early childhood—including play—could improve children's executive function and better their performance on standard academic testing. Her research also shows executive function can be improved in 4-5 year olds, ages that some researchers had thought was too early to try to improve executive function.

Carey and Zaitchik are conducting several experiments that explore how executive function relates to conceptual change. They are interested in exploring the possibility that providing training to enhance executive function can also facilitate conceptual change. They are also exploring whether diminished executive functioning might explain science and math difficulties in children at risk for school failure.

They are testing the hypothesis that executive function underlies the ability to achieve conceptual change in two very different groups. The first group is children who are engaged in new learning of specific science and math theories. The second group is healthy elderly adults who, despite decades of experience holding and using the theories involved, nonetheless make many of the same errors in reasoning that children do.

"This work has the potential to support and promote executive function in children in ways that will have broad and deep impacts on their learning and achievement," says Laura Namy, Developmental and Learning Sciences program director at NSF, pinning the research to important child development priorities.

Moreover, the research could have far-reaching importance to populations with particularly weak executive function, such as children with attention deficit hyperactivity disorder, a population also studied in the project, as well as disadvantaged children, aging adults and patients with Alzheimer's disease.

"That executive function enhancement can directly impact a mental process so far downstream as conceptual reasoning is potentially extraordinarily transformative," says Namy. "It implies that a relatively straightforward intervention, such as executive function training, has the potential to 'level the playing field' for children from disadvantaged backgrounds, for those with attention deficits and those experiencing age- and disease-related cognitive decline."

The relationship between executive function and conceptual change appears to be powerful, she says. "The goal of this investigation is to begin to discover why."

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