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Developmental Review 27 (2007) 172–223
DEVELOPMENTAL REVIEW
www.elsevier.com/locate/dr

The development of scientific thinking skills in elementary and middle school ☆

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Received 23 January 2006; revised 18 December 2006
Available online 9 March 2007

Abstract

The goal of this article is to provide an integrative review of research that has been conducted on the development of children's scientific reasoning. Broadly defined, scientific thinking includes the skills involved in inquiry, experimentation, evidence evaluation, and inference that are done in the service of *conceptual change* or scientific *understanding*. Therefore, the focus is on the thinking and reasoning skills that support the formation and modification of concepts and theories about the natural and social world. Recent trends include a focus on definitional, methodological and conceptual issues regarding what is normative and authentic in the context of the science lab and the science classroom, an increased focus on metacognitive and metastrategic skills, and explorations of different types of instructional and practice opportunities that are required for the development, consolidation and subsequent transfer of such skills.

Keywords: Scientific thinking; Scientific reasoning; Evidence evaluation; Experimentation; Investigation; Inquiry; Cognitive development

Children's scientific thinking has been of interest to both psychologists and educators. Developmental psychologists have been interested in scientific thinking because it is a fruitful area for studying conceptual formation and change, the development of reasoning and problem solving, and the trajectory of the skills required to coordinate a complex set of cognitive and metacognitive abilities. Educators and educational psychologists have

☆ I thank Carol Smith, David Klahr, Barbara Koslowski, Deanna Kuhn, Amy Masnick and two anonymous reviewers for helpful comments on previous drafts of this paper.
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doi:10.1016/j.dr.2006.12.001

shared this interest, but with the additional goal of determining the best methods for improving learning and instruction in science education. Research by developmental and educational researchers, therefore, should and can be mutually informative.

In an earlier review (Zimmerman, 2000), I pointed to the need for an increase in research at the intersection of cognitive development and science education, and that such synergistic research could help children to become better science students and scientifically literate adults. In the intervening years, there is evidence that educators and curriculum designers have been influenced by laboratory research on children's thinking. Concurrently, cognitive and developmental researchers have become aware of the objectives of educators and updated science education standards which recommend a focus on investigation and inquiry at all educational levels (e.g., American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996, 2000) and have used such knowledge in guiding research in both the lab and the classroom. Such a synergistic research strategy is especially important in light of current political and educational climate calling for "scientifically based research" and "evidence-based strategies" to support educational reforms (Klahr & Li, 2005; Li, Klahr, & Siler, 2006).

Scientific thinking is defined as the application of the methods or principles of scientific inquiry to reasoning or problem-solving situations, and involves the skills implicated in generating, testing and revising theories, and in the case of fully developed skills, to reflect on the process of knowledge acquisition and change (Koslowski, 1996; Kuhn & Franklin, 2006; Wilkening & Sodian, 2005). Participants engage in some or all of the components of scientific inquiry, such as designing experiments, evaluating evidence and making inferences in the service of forming and/or revising theories[1] about the phenomenon under investigation.

My primary objective is to summarize research findings on the development of scientific thinking, with a particular focus on studies that target elementary- and middle-school students. To preview, sufficient research has been compiled to corroborate the claim that investigation skills and relevant domain knowledge "bootstrap" one another, such that there is an interdependent relationship that underlies the development of scientific thinking. However, as is the case for intellectual skills in general, the development of the component skills of scientific thinking "cannot be counted on to routinely develop" (Kuhn & Franklin, 2006, p. 974). That is, even though young children demonstrate many of the requisite skills needed to engage in scientific thinking, there are also conditions under which adults do not show full proficiency. Although there is a long developmental trajectory, research has been aimed at identified how these thinking skills can be promoted by determining the types of educational interventions (e.g., amount of structure, amount of support, emphasis on strategic or metastrategic skills) that will contribute most to learning, retention and transfer. Research has identified what children are capable of with minimal support, but is moving in the direction of ascertaining what children are capable of, and

[1] Although there are many definitions of and disagreements about what counts as *theory*, this term will be used in an approach-neutral way to refer to an "empirical claim." This usage is consistent with Kuhn and Pearsall (2000) who outline four possible uses of the term theory or "theoretical claim," which range from least stringent such as *category* and *event claims* (e.g., "this plant died") to most stringent such as *causal* or *explanatory* claims which include an explanation of why the claim is correct (e.g., "this plant died because of inadequate sunlight"). The commonality among theoretical claim types is that "although they differ in complexity, each . . . is potentially falsifiable by empirical evidence" (p. 117).