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Brief Report

The puzzling difficulty of tool innovation: Why can't children piece their knowledge together?

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ABSTRACT

Tool innovation—designing and making novel tools to solve tasks—is extremely difficult for young children. To discover why this might be, we highlighted different aspects of tool making to children aged 4 to 6 years ($N = 110$). Older children successfully innovated the means to make a hook after seeing the pre-made target tool only if they had a chance to manipulate the materials during a warm-up. Older children who had not manipulated the materials and all younger children performed at floor. We conclude that children's difficulty is likely to be due to the ill-structured nature of tool innovation problems, in which components of a solution must be retrieved and coordinated. Older children struggled to bring to mind components of the solution but could coordinate them, whereas younger children could not coordinate components even when explicitly provided.

Introduction

Tools are an essential part of human everyday life (Vaesen, 2012); it is hard to consider how we might get through the day without them. Tool-using capacity is evident from a young age, with children as young as 2 years using simple tools such as spoons (Connolly & Dalgleish, 1989) and rakes (Brown, 1990). Children gain the majority of their tool behaviors by observing others. As such, social learning has been the focus of research into the development of children's tool use (Flynn & Whiten,

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2008, 2010; Lyons, Young, & Keil, 2007; McGuigan & Whiten, 2009; Nielsen, 2006) and also their tool making (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011). However, social learning cannot be a sufficient explanation for the development of all tool making because this would rule out the possibility of children (or anyone else) innovating novel tools (Nielsen, 2012). In contrast to findings when social learning is possible, recent findings suggest that innovation of a novel tool, by which we mean creating a novel tool to solve a problem, is extremely difficult for young children (Beck et al., 2011; Cutting, Apperly, & Beck, 2011). The focus of the current work was to determine what makes innovation so difficult. Our strategy was to highlight different components of the task solution to see whether this improved children's performance.

Children's tool innovation difficulties have previously been demonstrated in a series of experiments requiring children to innovate a tool in order to retrieve stickers (Beck et al., 2011; Cutting et al., 2011; Chappell, Cutting, Apperly, & Beck, 2013). Children had great difficulty in generating the solution to bend a pipecleaner into a simple hook tool to retrieve a bucket from a narrow vertical tube. Children under 5 years of age rarely innovated a hook tool, and by 8 years of age only around half of children were successful on this task. This difficulty in tool innovation extends to making other tools using pipecleaners (Cutting et al., 2011) and to other materials and methods of tool making (Cutting, Beck, & Apperly, 2013).

Children's difficulty with tool innovation is surprising because children appear to possess all of the relevant knowledge required to solve tool innovation tasks. Children are familiar with the properties of the materials, for example, the pliant nature of pipecleaners. In previous studies, children received manipulation exercises in which they bent pipecleaners prior to being given the tool-making task (Beck et al., 2011, Experiment 3; Cutting et al., 2011, Experiment 1). Practice with bending pipecleaners did not aid children on subsequent tool-making tasks. This suggests that if children did lack knowledge about the properties of pipecleaners (or other materials), this is not sufficient to explain their difficulty.

As well as seemingly understanding the properties of pipecleaners and the fact that they are allowed to manipulate them, children also appeared to have the required knowledge about the physics of the problem they faced. In the hook task, children appeared to understand that a hook would be the most functional tool; in a tool selection version of the task, children as young as 4 years chose the hooked tool over the straight tool first when their task was to retrieve a bucket from a vertical tube using pre-made tools (Beck et al., 2011, Experiment 1). Furthermore, children could also recognize a functional tool when shown how to make one: After initial failure on the hook innovation task, children readily manufactured a hook tool and used it correctly when shown a hook-making demonstration (Beck et al., 2011; Cutting et al., 2011). Note that children were only shown how to *make* the required tool; they were not given a demonstration as to how to *use* it.

Taken together, this evidence suggests that it is not a simple lack of knowledge that limits children's performance. Children understand the properties of the materials they are given and are aware that they are allowed to manipulate them. Children understand the physics of the task and can recognize a hook as the most functional tool. So, if children possess all of this knowledge, why do they find tool innovation so difficult?

One possibility is that children's difficulty with tool innovation could be due to its ill-structured nature. Although there is no single agreed-on definition of what constitutes an ill-structured problem, a generally agreed-on framework is that an ill-structured problem is one that is missing information from its start state, goal state, or information regarding the transformation required to go between the two (Goel & Grafman, 2000; Wood, 1983). Following this definition, tool innovation is an ill-structured problem; children are given the start state (the apparatus and the materials) and told that the goal is to retrieve the sticker, yet they are given no information regarding how they should go about this task. Compare this with Beck and colleagues' (2011, Experiment 1) well-structured tool selection task in which young children readily succeed. In this task, children are given the start state (the apparatus and materials) and the goal state (retrieve the sticker) and are given the choice between two possible means for effecting a transformation (use the straight pipecleaner or use the hooked pipecleaner). When information about the start state, goal, and means were provided, children found it trivially easy to retrieve the bucket.

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