Tool innovation may be a critical limiting step for the establishment of a rich tool-using culture: a perspective from child development.

Sarah R. Beck[1], Jackie Chappell[2], Ian A. Apperly[1], Nicola Cutting[1]

[1]School of Psychology, University of Birmingham, UK

[2]School of Biosciences, University of Birmingham, UK

This is a commentary on a target article by K. Vaesen The cognitive basis of human tool use. In press, October 2011

Abstract:

Recent data show that human children (up to 8 years old) perform poorly when required to innovate tools. Our tool rich culture may be more reliant on social learning and more limited by domain general constraints such as ill-structured problem-solving than otherwise thought.

Main text:

Vaesen is right to identify the tension between the need for reliable conservation of tool forms and the need for deviation from reliable reproduction if new tools are to be created. Yet, he does not draw a clear enough distinction between the cognitive demands of tool *innovation* and other aspects of tool use. Tool innovation is seen when individuals make a tool to solve a problem without learning socially or having seen a model solution. Where Vaesen refers to human children's tool use, it is to emphasise human beings' strengths from a very early age (e.g. section 4). However, taking a developmental perspective on human tool use has shown that tool innovation may be particularly difficult for human children compared to using pre-made tools. Successful innovation in older children and adults is needed to explain the unique richness of human tool culture, while the difficulty of innovation observed in human children casts new light on the importance of other abilities, such as social learning, for retaining hard-won innovations.

We (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011) tested human children on a tool making task based on Weir, Chappell, and Kacelnik's (2002) wire bending problem. This task was originally made famous by the successes of a New Caledonian crow (*Corvus moneduloides*) and more recently rooks (*Corvus frugilegus*) (Bird & Emery 2009). Having previously used a hook to retrieve a bucket from a tall vertical tube, these corvids were then able to fashion a straight piece of wire to make a hook to solve the task: they used novel means to make a familiar tool. We questioned whether children would innovate a novel tool, critically without having seen the solution to the task (a hook). Children up to 5 years old found it near impossible to innovate a novel tool to solve this task and it was not until 8 years of age that the majority of children passed (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011). Children's difficulty was replicated on a task requiring them to unbend a wire to make a long, straight tool (Cutting, Apperly, & Beck, 2011) and on tool innovation tasks involving other materials and other transformations (adding and subtracting from the tool object, as well as bending, Cutting, Beck, & Apperly, under submission). The results could not be attributed to a lack of causal understanding: young children readily used a pre-made hook tool to solve the vertical tube task (Beck et al., 2011, Experiment 1). Nor could they be explained by a pragmatic resistance to adapting the materials: children's difficulties remained in the face of ample encouragement to reshape the pipecleaner. We gave children pre-trial experience manipulating the materials, encouraged them to 'make something', and demonstrated tool-manufacture on a different task (see Cutting et al., 2011).

Children's ability to select an appropriate pre-made tool indicates that they did not lack the causal knowledge to solve the task (in Vaesen's terms analogical causal reasoning, see section 4). Furthermore, when an adult demonstrated to the child how to make an appropriate tool, almost all children (97%) found it apparently trivially easy to *manufacture* their own tool and fish the bucket from the tube (Beck et al., 2011). Why, then, is tool *innovation* so late-developing?

One possibility is that an over-reliance on social learning and/or teaching (see sections 7 and 8) prevents children from innovating for themselves. We agree with Vaesen that human children are experts at learning from others. But a species that evolves to pass on information so efficiently to new learners does so at a cost. It is inefficient and possibly counter-productive for children to try to generate their own solutions to problems as well as adopt them from others. At least in childhood, if not also in adult life, the ability to innovate may be sidelined in preference to learning from the more experienced individuals who share our goals and are motivated to collaborate with us (see section 9).

However, we doubt that this will be the full explanation. Vaesen argues that developing an advanced technological culture requires trial-and-error learning and causal understanding. In addition, we suggest that tool innovation is challenging because it makes distinctive demands on executive function. In cognitive and neuropsychological investigation of executive function, "ill-structured" problems are tasks that do not exhaustively define the means of getting from the start point to the goal, but instead require participants to generate such structure for themselves (Goel, 1995). From this perspective tool innovation is clearly an intrinsically "ill-structured" problem: participants know the goal (e.g., of retrieving the bucket from the tube), and their start point includes the necessary materials (e.g., the wire), but they must generate for themselves the strategy of using the materials to make the necessary tool. As ill-structured problem solving has been associated with late maturing areas of medial prefrontal cortex (Dumontheil, Burgess, & Blakemore, 2008), it is likely to be limited in young children. Thus, unlike trial-and-error learning and causal understanding, which may be observed in young children, difficulty with ill-structured problem-solving may explain why children find tool-innovation so surprisingly difficult.

Recognising that tool-innovation might be an intrinsically difficult problem helps us understand why the capacity for social learning is so important for the development and maintenance of a tool-using culture in both humans and non-human animals: social learning avoids each individual having to "reinvent the wheel" for themselves. Furthermore, if tool innovation requires ill-structured problem-solving, this might help explain why tool cultures in non-human animals are less rich than those of humans. Importantly, though, this leaves open the question of how non-human animals develop the tools that they have. One possibility is that they rely only on trial-and-error, the useful products of which are maintained through social learning. Another possibility is that tool cognition provides a window onto non-human animals' ill-structured problem-solving, through which we might gain important understanding about the origins of executive control.

References:

Beck, S.R., Apperly, I.A., Chappell, J., Guthrie, C., & Cutting, N. (2011). Making tools isn't child's play. *Cognition, 119,* 301-306.

Bird, C. D. & Emery, N. J. (2009). Insightful problem solving and creative tool modification by captive nontool-using rooks. *Proc Natl Sci USA, 106,* 10370-10375.

Cutting, N., Apperly, I.A., Beck, S.R. (2011). Why do children lack the mental flexibility to innovate tools? *Journal of Experimental Child Psychology, 109,* 497-511.

Cutting, N., Beck, S.R., & Apperly, I.A. (under submission). Is there a complexity hierarchy in human children's tool making?

Dumontheil, I., Burgess, P.W., & Blakemore, S.J. (2008). Development of rostral prefrontal cortex and cognitive and behavioral disorders**.** *Developmental Medicine and Child Neurology*, *50,* 168-181.

Goel, V. (1995). *Sketches of thought.* Cambridge, MA: MIT Press.

Weir, A.A.S., Chappell, J., & Kacenik, A. (2002). Shaping of hooks in New Caledonian Crows. *Science, 297,* 981.

White, S. J., Burgess, P. W., & Hill, E. L. (2009). Impairments on ''open-ended'' executive function tests in autism. *Autism Research, 2,* 138–147.