

## **Creation Across Culture: Children's Tool Innovation Is Influenced by Cultural and Developmental Factors**

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### Abstract

Prior research suggests that human children lack an aptitude for tool innovation. However, children's tool making must be explored across a broader range of tasks and across diverse cultural contexts before we can conclude that they are genuinely poor tool innovators. To this end, we investigated children's ability to independently construct three new tools using distinct actions: adding, subtracting and reshaping. We tested 422 children across a broad age range from five geographic locations across South Africa ( $N = 126$ ), Vanuatu ( $N = 190$ ) and Australia ( $N = 106$ ), which varied in their levels of exposure to Westernized culture. Children were shown a horizontal, transparent tube that had a sticker in its middle. Children were sequentially given each incomplete tool, which when accurately constructed could be used to push the sticker out of the tube. As predicted, older children were better at performing the innovation tasks than younger children across all cultures and innovation actions. We also found evidence for cultural variation: while all non-Western groups performed similarly, the Western group of children innovated at higher rates. However, children who did not innovate often adopted alternate methods when using the tools that also led to success. This suggests that children's innovation levels are influenced by the cultural environment, and highlights the flexibility inherent in human children's tool use.

*Keywords:* tool innovation, cross-cultural, innovation, tool manufacture, cognitive development, cumulative culture

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1           Humans generate countless solutions to address the fundamental  
2 problems of survival, including storing food, retaining water and making shelter.  
3 These solutions, despite being functionally similar, often differ radically in  
4 structure and design across communities, highlighting the creativity and  
5 resourcefulness of human innovation. Yet the flexibility apparent in modern  
6 humans' technologies appears absent from the tool creation of young children.  
7 While children are adept tool users (employing an object in the environment to  
8 help achieve a goal; B. B. Beck, 1980; Brown, 1990; Casler & Kelemen, 2005;  
9 Chen, Siegler, & Daehler, 2000; Connolly & Dalgleish, 1989; McGuigan & Whiten,  
10 2009; Reindl, Beck, Apperly, & Tennie, 2016) and skilled manufacturers (making  
11 tools after watching a demonstrator; S. R. Beck, Williams, Cutting, Apperly, &  
12 Chappell, 2016), they appear to lack the capacity for independent tool creation  
13 and design (S. R. Beck, Apperly, Chappell, Guthrie, & Cutting, 2011). Tool  
14 innovation, or the making of a novel tool without observing how to do so by  
15 another, is a comparatively late developing ability (Cutting, 2013). Children  
16 younger than 7 years of age struggle to create simple tools to achieve a goal if  
17 they are given no clues about how the tool could be created or what it might look  
18 like (S. R. Beck et al., 2011; Cutting, Apperly, & Beck, 2011; Neldner, Mushin, &  
19 Nielsen, 2017). Even when information is provided on one of these two  
20 dimensions, young children struggle to generalize their new knowledge to novel  
21 contexts, with only 14-22% of children doing so (S. R. Beck et al., 2014). Adults,  
22 by contrast, find these tasks relatively easy, performing close to ceiling (Beck et  
23 al., 2011).

24           While current evidence suggests low performance in young children,  
25 major limitations in the field of tool innovation development must be addressed

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26 before we can conclude that young children are poor tool innovators. For  
27 example, children should be provided with a variety of tasks in order to give  
28 them reasonable opportunity to display their innovative abilities. To date, most  
29 work has focused on tasks requiring the formation of hook-shaped tools, using  
30 the same material type (pipecleaners; S. R. Beck et al., 2011; S. R. Beck et al.,  
31 2014; Cutting et al., 2011; Neldner et al., 2017). Similarly, most tasks have  
32 required one type of manufacture action in order to create the successful tool:  
33 reshaping the material from one static shape into another (e.g. from a straight  
34 pipecleaner into one with a hook). However, multiple materials and methods  
35 might be employed to solve even a simple tool-use problem, as reflected by the  
36 diversity of toolkits present in human communities around the world. In order to  
37 examine tool creation in a more ecologically-representative manner, children's  
38 innovation must be examined across a range of tasks and contexts.

39         How does one create a simple tool? Although little investigation has  
40 examined the nature of children's tool-making, the types of actions employed by  
41 animals has been meticulously outlined. Beck (1980) collated a comprehensive  
42 list of tool manufacture behaviors observed in wild populations of nonhuman  
43 animals, categorizing them broadly into four modes of action (Kacelnik, Chappell,  
44 Weir, & Kenward, 2006). These comprised: 1) detachment: the removal of a tool  
45 from another object by the severing of a fixed attachment; 2) subtraction: the  
46 removal of unnecessary attachments away from a core object to make it a tool; 3)  
47 addition: the combination of more than one object to form a tool; and 4)  
48 reshaping: changing the overall structure of an object to create a tool (Shumaker,  
49 Walkup, & Beck, 2011). He noted that detachment was the most commonly  
50 observed action type, and plausibly the easiest. In wild populations of

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51 chimpanzees and orangutans, detachment of sticks and subtraction of leaves  
52 from branches occurs frequently (B. B. Beck, 1980; Boesch & Boesch, 1983;  
53 McGrew, 1974; Shumaker et al., 2011; van Schaik et al., 2009), and has been  
54 observed in capuchin monkeys (Costello, 1987; Westergaard & Fragaszy, 1987a,  
55 1987b) and golden lion tamarins (Stoinski & Beck, 2001). In contrast, reshaping  
56 only occurs in some ape populations in the form of leaf sponging (scrunching  
57 multiple leaves down to make a sponge for soaking up water; Biro, Sousa, &  
58 Matsuzawa, 2006; Sanz & Morgan, 2007; Shumaker et al., 2011; van Schaik et al.,  
59 2003; van Schaik et al., 2009; Whiten et al., 1999, 2001) and the fashioning of  
60 sticks into sharp ends for hunting (Pruetz & Bertolani, 2007). Accounts of  
61 addition have only been observed in captive contexts, such as the chimpanzee  
62 Sultan combining two rods together to reach a suspended banana (Köhler, 1917,  
63 1925; Lethmate, 1978), and experiments indicating that chimpanzees find  
64 subtraction easier than addition when manufacturing tools, but are capable of  
65 performing both (Bania, Harris, Kinsley, & Boysen, 2009). Arguably then,  
66 conceptualizing the restructuring of an object or its combination with another  
67 might require more cognitive resources than when simply taking elements away  
68 from it.

69         To date, only one investigation into children's tool innovation across a  
70 range of action types has been reported, wherein children aged 4-7 years old  
71 were required to extract a reward out of the middle of a transparent, horizontal  
72 tube (Cutting, 2013). The tool required to achieve the desired result was a long  
73 straight tool, which either needed to be extracted from a bundle of shorter sticks  
74 (detachment), constructed by removing two cross-pieces of wood from a longer  
75 dowel (subtraction), created by joining three small dowels together (addition),

76 or made by unbending a V-shaped pipecleaner (reshaping). Children found  
77 detachment easy, but no differences existed amongst the other actions, where  
78 new tools were innovated at very low rates. Older children were nevertheless  
79 more adept at solving the subtract and reshape tasks than younger children,  
80 demonstrating that children's ability to innovate tools improves with age.  
81 Cutting thus concluded that there was little evidence for young children's  
82 proficiency in tool innovation, but that older children demonstrate greater skill.  
83 However, the presence of distractor items during testing may have increased the  
84 cognitive load on the children, thereby impeding performance. Similarly,  
85 innovation was only considered to have occurred if children constructed the tool  
86 correctly prior to its first insertion into the tube, meaning children who might  
87 have innovated their tool following a first attempt and necessary exploration on  
88 the task (Lancy, 2017) were considered unsuccessful. These limitations may  
89 have combined to obscure children's inherent tool innovation abilities. These  
90 were to be addressed using a bolstered methodology in the present study<sup>1</sup>.

91 Current research on tool innovation in humans should also be viewed in  
92 light of a conspicuous caveat; that as with most published research in  
93 developmental psychology (Nielsen, Haun, Kartner, & Legare, 2017) study  
94 samples derive almost exclusively from Westernized, educated, industrialized,

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<sup>1</sup> We chose to remove distractor items and only present the tool to be innovated upon. We also chose to code for innovations that occurred after inserting the tool into the tube as we recognize that innovative behavior often follows exploration of a task (Riede, Johannsen, Högberg, Nowell, & Lombard, 2018). Exploration allows for children to become familiar with materials, identify the affordances within tools, and gain an understanding of the causal relations involved in a certain task (Bjorklund & Gardiner, 2011). In this task children likely benefit from observing that the incomplete tool does not work in its current form, and this spurs on subsequent questions of how the tool needs to change in order for it to successfully fit in the tube.

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95 rich and democratic (WEIRD) societies (Henrich, Heine, & Norenzayan, 2010,  
96 although see; Neldner et al., 2017; Nielsen, Tomaselli, Mushin, & Whiten, 2014).  
97 WEIRD children not only comprise a very small percentage of the world's  
98 children, but they differ distinctly from children of other cultures on a range of  
99 dimensions, and are frequently considered outliers on the scale of human  
100 performance (Henrich et al., 2010). For instance, their upbringing typically  
101 features more formal and individually directed teaching, and less observational  
102 and trial-and-error based learning than non-WEIRD cultures (Bakeman,  
103 Adamson, Konner, & Barr, 1990; Clegg & Legare, 2016; Hewlett, Fouts, Boyette, &  
104 Hewlett, 2011; Lancy, 2017; Little, Carver, & Legare, 2016). WEIRD societies also  
105 emphasize the self more than the group, and favor divergent thinking in young  
106 children, rather than conformity (Clegg, Wen, & Legare, 2017; Harkness et al.,  
107 2007; Mesoudi, Chang, Murray, & Lu, 2015; Suizzo, 2007; Tobin, Hsueh, &  
108 Karasawa, 2009; Wen, Clegg, & Legare, 2017), which might see their individual  
109 inventiveness improve. Tool using and tool making behaviors vary distinctly  
110 across human societies (Ambrose, 2001; Borgerhoff Mulder & Schacht, 2012;  
111 Foley & Lahr, 2003; Henrich & McElreath, 2003; Hodder & Hutson, 2003;  
112 Schlereth, 1985; Winterhalder & Kennett, 2006), with such differences reflecting  
113 variation in environmental pressures and cultural practices (Henrich et al.,  
114 2010). It is reasonable then to expect that sociocultural environments will also  
115 influence tool innovation outcomes. Before we are to understand how tool  
116 innovation emerges within human development, and the sociocultural factors  
117 that affect it, more investigation must occur across a diversity of cultures.

118         To this end, the current study takes a cross-cultural approach to track the  
119 emergence of tool innovation behaviors in children across five different cultural

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120 milieus, examining whether developmental patterns show concordance or  
121 variability across societies varying markedly in ecology (Kline, Shamsudheen, &  
122 Broesch, 2018). Our study sites comprised of communities in which the authors  
123 KT, MN and JD have established connections. The first study site was Vanuatu, a  
124 chain of over 80 islands in the South West Pacific with a population exceeding  
125 240,000 living in a dozen main islands. Almost 80% of Ni-Vanuatu people  
126 practice subsistence horticulture, a small amount of animal husbandry, and  
127 fishing (Dixson et al., 2017). We collected data from children living on Tanna  
128 island ( $N = 190$ ), one of the southern-most and remote populations in Vanuatu.  
129 Our second study sites were two small-scale communities of Kalahari Bushmen<sup>2</sup>  
130 from South Africa ( $N = 126$ ) in Platfontein and the Kgalagadi. Bushmen people  
131 are historically hunter-gatherers, but present Platfontein populations live in  
132 townships outside of the capital city of the Northern Cape state in South Africa.  
133 Kgalagadi bushmen live in small communities of less developed townships in the  
134 North-Western corner of the Northern Cape. Finally, we collected data from  
135 Australian children from a large metropolitan city ( $N = 106$ ), all of whom were  
136 educated and comparatively affluent.

137         In addition to ecological variation, our samples differed in their exposure  
138 to Westernized culture, access to education and exposure to novel artifacts. Our  
139 first Ni-Van sample came from the remote highland villages of Ikunala and Yakel,  
140 where education follows traditional *Kastom* practices and formal schooling is  
141 seldom attended; most children remain in the villages and help their families in

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<sup>2</sup>We refrain from using the term *San* to refer to our Kalahari participants. *San* is a controversial, externally imposed term derived from a Nama word meaning “bandit.” The people in the communities we visit call themselves Bushmen and, with respect, so do we. Where possible, we utilize the names of the communities.



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142 farming practices. As a result, these children are most familiar with tools made  
143 from natural materials that are used for horticulture, such as wooden digging  
144 sticks and woven baskets. In contrast, our second sample of Ni-Vanuatu children  
145 was from the township of Lenakel, where people live in both traditional houses  
146 with small subsistence gardens and more modern dwellings. Here adults may  
147 work for salaries at the Ports, markets or in commercial agriculture. Children  
148 were recruited from the Catholic mission primary school, where they are  
149 exposed to some Western tools (i.e. blocks and pens) but limited educational  
150 curriculum, as well as with traditional and Western tools in the home (ie. axes  
151 and cooking pots). Participants from both our South African communities had  
152 greater access to schooling than our Ni-Vanuatu participants, although the  
153 systems available were rudimentary. The sample of Kgalagadi bushmen live in  
154 remote traditional communities with locally-run creches and schools. In  
155 contrast, Platfontein Bushmen live on the outskirts of a capital city. Here,  
156 schooling is more formalized than in the Kgalagadi sample and children are  
157 exposed to more Western artifacts in the classroom (e.g. animal figurines, blocks  
158 and dolls).

159 Variations across such factors may also lead to differences in children's  
160 propensity to innovate. Past cross-cultural research has found a delay in onset of  
161 theory of mind among Ni-Vanuatu children (Dixson et al., 2017) and a later onset  
162 in mental forecasting among South African bushmen children (Redshaw et al.,  
163 2018) between the ages of 3 to 6 years compared to preschool-educated  
164 Australian children. This may be because exposure to Western education at an  
165 early age equips children to better grasp the linguistic structures and concepts  
166 that might underpin Westernized experimental tasks (Dixson et al., 2017;

167 Redshaw et al., 2018), and provides greater confidence interacting with Western  
168 experimental apparatuses due to greater exposure to novel artifacts (Riede et al.,  
169 2018). In an attempt to capture such variation between our rural and more  
170 urbanized samples, we analyzed each cultural milieu separately.

171 We made no specific predictions regarding cultural differences between  
172 our samples. However, following previous research reporting that older children  
173 are more successful innovators than younger children (S. R. Beck et al., 2011; S.  
174 R. Beck, Chappell, Apperly, & Cutting, 2012; S. R. Beck et al., 2016; Chappell,  
175 Cutting, Apperly, & Beck, 2013; Cutting et al., 2011; Cutting, Apperly, Chappell, &  
176 Beck, 2014; Neldner et al., 2017), we did predict that tool innovation proclivity  
177 would increase with age across cultures.

178 Method

#### 179 *Participants*

180 In total, 202 Ni-Van children from Vanuatu, 106 Western children from  
181 Australia and 126 Bushmen children from South Africa were included in this  
182 experiment, for a total of 434 children and 1, 244 observations made across  
183 culture for three tool types<sup>3</sup>. Participant demographics for each sample are  
184 summarized in Table 1. An additional 16 children were excluded due to  
185 excessive shyness (2 Bushmen; 2 Ni-Van), experimenter error (4 Bushmen; 2 Ni-  
186 Van; 2 Western), or not reaching the adequate age range (2 Bushmen; 2 Ni-Van).  
187 The lower limit of 3 years of age replicated previous tool innovation studies, and  
188 the upper limit of 9 years of age was determined to allow for analysis across a  
189 broad developmental trajectory, as Western samples have reported significant

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<sup>3</sup> Using a simple correlation power analysis, a sample size of over 400 children provided close to 100% chance of detecting a medium age effect ( $r = .30$ ).

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190 improvements occurring on tool innovation tasks between 7-8 years of age<sup>4</sup>. All  
191 children who wished to be tested in the Vanuatu and South Africa field sites were  
192 given the opportunity to do so, which lead to variation in total cell sizes for each  
193 age group across samples<sup>5</sup>. Ethical approval<sup>6</sup> for all measures was obtained from  
194 the university and community and cultural boards in South Africa and Vanuatu  
195 before testing commenced. Community members fluent in the local language of  
196 each field site were recruited to translate task instructions during testing. Each  
197 translator back-translated the instructions to another community member to  
198 check for accuracy in translation prior to testing.

199         *Western sample.* The sample of Western children was recruited in the  
200 foyer of a science museum in [CITY OMMITTED] or through the parent database  
201 of the university laboratory. [CITY OMMITTED] is a large capital city with a  
202 population of 2.35 million. Young children attend preschool at age four, and  
203 curriculum-based schooling is compulsory until 15 years of age (Australian  
204 Bureau of Statistics, 2017). While specific demographic information was not  
205 collected for this sample, previous unpublished data collected at the science  
206 museum and laboratory indicates that the majority of participating families are  
207 from middle-class socioeconomic backgrounds and identify as Caucasian. [CITY  
208 OMMITTED] itself is a Westernized city, and children are typically exposed to TV,  
209 commercial toys and mainstream tools on a daily basis at school and in the home.

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<sup>4</sup> We did not record age in number of months for any of our samples, as this information is typically unavailable in Bushmen or Ni-Van communities.

<sup>5</sup> We had access to crèches and a primary school in Platfontein but no secondary schools were available for testing, so the upper age limit for this group was 6 years old.

<sup>6</sup> Ethical clearance number 2014001272 for project entitled "Tool innovation abilities of young children: A question of prior experience and material type".

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210            *Ni-Van sample (villages)*. Ni-Van children from village communities were  
211 recruited from two communities on the island of Tanna. Roughly 300 people live  
212 in the highland villages of Ikunala and Yakel. These villages follow traditional  
213 *Kastom* practices and reject Western influence. They rely on subsistence farming  
214 for their livelihood -all housing and gardening implements are fashioned from  
215 natural materials such as bamboo, palms, vines and hardwoods from the  
216 surrounding forest. Very few children attend school; most children remain in the  
217 villages and help their families in farming practices, including planting,  
218 harvesting and caring for pigs and chickens.

219

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220 **Table 1.** Participant demographics across the five community samples tested.

Participant group	Western city ( <i>Australia</i> )	Ni-Van villages ( <i>Vanuatu</i> )	Ni-Van township ( <i>Vanuatu</i> )	Platfontein Bushmen community ( <i>South Africa</i> )	Kgalagadi Bushmen community ( <i>South Africa</i> )
3-year-olds ( <i>m, f</i> )	17 (10,7)	2 (0,2)	4 (2,2)	14 (10,4)	13 (9,4)
4-year-olds ( <i>m, f</i> )	13 (8,5)	32 (19,13)	4 (1,3)	8 (5,3)	12 (6,6)
5-year-olds ( <i>m, f</i> )	15 (7,8)	22 (18,4)	8 (7,1)	10 (6,4)	8 (5,3)
6-year-olds ( <i>m, f</i> )	28 (11,17)	16 (11,5)	22 (16,6)	9 (4,5)	19 (8,11)
7-year-olds ( <i>m, f</i> )	14 (11,3)	8 (5,3)	21 (9,12)	-	18 (4,14)
8-year-olds ( <i>m, f</i> )	10 (5,5)	10 (4,6)	12 (5,7)	-	3 (0,3)
9-year-olds ( <i>m, f</i> )	9 (5,4)	22 (14,8)	7 (3,4)	-	12 (8,4)
Total ( <i>m, f</i> )	106 (57,49)	112 <sup>a</sup> (71,41)	78 (43,35)	41 (25,16)	85 (40,45)

221 <sup>a</sup> An additional 12 children were included in the overall analyses from the Ni-Van town sample,  
 222 however these children's ages were unknown and are not reported here.

223  
 224 *Ni-Van sample (township).* Ni-Van children from townships were recruited  
 225 at a Catholic mission primary school located in the coastal town of Lenakel on  
 226 Tanna Island. This school provides some lessons to children from both *Kastom*  
 227 village communities and Christian families living in Lenakel. Schools in Tanna  
 228 loosely follow a British education system, and rely heavily on volunteer teachers

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229 with training overseas but also employ Melanesian teachers. Lessons are taught  
230 in Bislama, Vanuatu's national creole language. Children from Lenakel live in a  
231 mix of traditional thatched dwellings and basic concrete and corrugated iron  
232 buildings. While the majority of food is sourced from private gardens or markets,  
233 adults may work for income in the fishing, coffee or labor industries.

234 *Platfontein Bushmen sample.* Platfontein bushmen children were from the  
235 !Xun or Khwe communities, living in the settlement of Platfontein. Platfontein is  
236 situated on the outskirts of Kimberley, the capital city of the Northern Cape state  
237 in South Africa. These communities have endured a trying history of  
238 displacement and neglect. In 1990, the !Xun and Khwe people were relocated  
239 from their homelands in Namibia and Angola to South Africa following the end of  
240 the border war, where they had been employed as trackers by the South African  
241 Defence Force (Kleinbooi, 2007). At first, they were assigned to the tented camp  
242 of Schmidtsdrift and endured difficult living conditions alongside each other.  
243 Following return of the lands of Schmidtsdrift back to their traditional owners,  
244 the !Xun and Khwe people were relocated to Platfontein in 2003 by the South  
245 African Government, where they remain today. The township here consists of  
246 rudimentary concrete housing and self-built structures. Unemployment and  
247 poverty remain high. Only 6% of adults complete their senior high school  
248 certificate (Tomaselli & Ewing, 2012). Children here may attend Christian  
249 community crèches and government-funded schools, although regular  
250 attendance is low. Some houses have a TV and some adults own cellphones.  
251 Children use makeshift toys for play with their peers, including tyres and sticks  
252 to run races, and making footballs from paperbark and grass. However within  
253 schools they are also exposed to more commercial toys such as blocks and dolls.

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254            *Kgalagadi Bushmen sample. Kgalagadi bushmen* children were recruited  
255 from two settlements within the region of Kgalagadi Transfrontier Park (KTP).  
256 The Khomani San community repossessed the land in this region in 1999  
257 following a restitution land claim. The Khomani people have faced displacement,  
258 violence and the loss of many cultural practices through the reign of apartheid  
259 and colonialism in South Africa (Grant, 2011; Tomaselli, 2005). The Khomani San  
260 settlements consist of basic concrete buildings, self-built thatched huts and  
261 informal housing, although there is no running water, electricity or sanitation.  
262 There are government-funded crèches and schools within the community, which  
263 employ local teachers and assistants, however attendance is inconsistent.  
264 Children have exposure to Western toys in the crèches and schools, and often  
265 play football outside, but are relatively isolated from Western society (Tomaselli,  
266 2005).

### 267 *Materials*

268            The apparatus consisted of three 30 cm x 3.5 cm diameter plexiglass  
269 tubes that were mounted horizontally on a platform. A 4 cm wide pompom was  
270 placed in the middle of the tube, with a sticker attached. Three tools were used.  
271 The Subtract tool was a 30 cm long x 1.5 cm wide plastic rod that had two 3 cm  
272 rods attached perpendicular to the main rod with strong magnets (refer Figure  
273 1). Each could be pulled away from the main tool with a little force to leave one  
274 long, rigid tool. The Add tool consisted of three 10 cm length x 1.5 cm width  
275 plastic rods. Each rod had a hole containing a magnet at one end and a metal  
276 dowel at the other end, allowing the rods to be joined together. Each rod could be  
277 combined to create one long, rigid tool. The Reshape tool was a 30 cm long x 1  
278 cm wide rubber curve with flexible wire in its interior. The Reshape tool was

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279 presented in an S-shape, but each end could be straightened out to become a  
280 long, straight tool. We removed the Detach tool from our battery, as it was found  
281 from previous research that young children found this action trivially easy, and  
282 solved it at ceiling (Cutting, 2013). We thus decided to focus on finding variation  
283 between the more complex tool-making actions.

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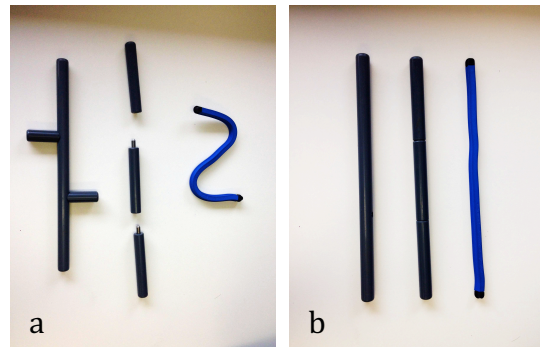
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292 **Figure 1.** Subtract, Add and Reshape tools provided, in their a) presenting state  
293 and b) innovated form.

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296 *Procedure.* Tools were presented in a counterbalanced randomized order  
297 in an A-B-C, B-C-A, or C-A-B pattern, such that each child participated in all tool  
298 conditions.

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*Innovation phase.* Before testing commenced, the study was explained to  
parents, community leader or the chief of the village, and written consent or  
verbal consent obtained. All children were tested out of view of other children on  
a mat, seated across from the experimenter (and translator, for Ni-Van and  
Bushmen children; see Figure 2). Western children were tested within the foyer  
of a science museum or a university laboratory. Ni-Van children were tested in a  
thatched house in the villages and inside a relief tent in the township community.  
Bushman children were either tested outside a crèche or school building. The  
experimenter pointed at the plexiglass tube to show the sticker inside. The child  
was told that if they could get the sticker out of the tube, they could keep it. The



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308 experimenter then presented the first tool in its unmodified form. The child was  
309 told that maybe they could use that item to get the sticker out. All children were  
310 given one minute to retrieve the toy doing whatever they liked. However, if  
311 children ceased to interact with the task or perseverated with the same action  
312 for a 20 second duration, the trial was terminated. If children succeeded in  
313 retrieving the sticker they were given it and moved on to the next innovation  
314 trial. However, if children failed to retrieve the sticker, they proceeded to a  
315 partial demonstration phase. Each child received all three tools across three  
316 trials.

317 *Partial demonstration phase.* In this phase, children were shown the  
318 action required on one end of the tool. The experimenter removed one dowel on  
319 the Subtract tool, added two pieces of the Add tool together, and straightened  
320 one of the two bends of the Reshape tool. This phase served to examine whether  
321 children could take the action they had observed and apply it to the entirety of  
322 the tool to create the ideal tool. This is considered tool modification, rather than  
323 tool innovation, because children have observed the experimenter perform the  
324 action previously. If children still did not succeed on the task, they proceeded to  
325 the full demonstration phase.

326 *Full demonstration phase.* In this phase, the experimenter completed the  
327 making of the ideal tool, by doing the final action on the other end of the tool  
328 (removing the final dowel on the Subtract tool, adding the final piece in the Add  
329 tool, and straightening the final part of the Reshape tool). This phase served to  
330 check that children were capable of recognizing the ideal tool as appropriate for  
331 the task and effectively using it to retrieve the sticker. All children were given a

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

332 prize at the conclusion of testing: armbands for the Western children and t-shirts  
333 for the Ni-Van and Bushmen children.

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344 **Figure 2.** The experimental setup in a) [CITY OMITTED] science museum, b)  
345 Ni-Van village communities and c) Platfontein Bushmen communities.

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347 *Coding.* Dependent variables were coded for each of the three test phases

348 as follows: a) whether the appropriate innovation<sup>7</sup> was made on the tool

349 (yes/no) b) whether the innovation occurred before the first insertion of the tool

350 into the tube (yes/no), c) whether the sticker was successfully retrieved

351 (yes/no), and d) whether success occurred by innovation<sup>8</sup> (yes/no). Inter-rater

352 reliability coding occurred on 10% of videos for a strong agreement rating

353 (Cohen's kappa = .945).

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<sup>7</sup> Note that tool innovation only occurred within the innovation phase – following the partial and full demonstrations, if children made an action on the tool it was considered a tool modification, as they had observed the action by the experimenter previously.

<sup>8</sup> This variable allowed us to distinguish between successful retrieval occurring by innovation, or by using an alternate strategy that did not require altering the tool's current form.

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**Results**

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Testing in the Western community revealed relatively high rates of tool innovation across the tasks, with the majority of children successfully innovating a tool to solve the target problem (see Figure 3). However, when the task was taken to Vanuatu and South Africa, roughly 40% of children utilized force or multi-tool use strategies to solve the reshape and add tasks respectively using the tools in their current state, rather than innovating on them. In the reshape task, children would repeatedly push the reshape tool against the inside of the tube with force until it straightened. In the add task, they would slide each dowel inside the tube one after the other in order to push the reward out, without combining the parts together to create one long tool. These actions were not classified as directed tool innovation. This meant that comparisons across the three tasks were not feasible, as no comparable alternate solution was possible for the Subtract task – it could only be solved through tool innovation. We therefore analyzed each action type separately.

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Before conducting main analyses, children's performance in cultural milieus in Vanuatu and South Africa were compared to examine similarities or differences in responding. Some statistical differences in innovation performance were detected, and each sample was analyzed separately. This meant that 5 groups were used for the main analysis – the Western group, the Vanuatu village group, the Vanuatu township group, the Platfontein Bushmen group and the Kgalagadi Bushmen group. For a full breakdown of frequency data, refer to supplemental materials.

*Main analysis.*

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378 Children's success and innovation responses were entered into a series of  
379 binomial logistic generalized linear models using the GLIMMIX procedure in SAS  
380 9.4 (Stroup, 2012). The dependent variable (yes/no) was classified as binomial,  
381 and thus the models were tested against a binomial distribution with a logit link  
382 function. Each tool was analyzed separately, comparing models including all  
383 unique combinations of the fixed effects of age (3-9 years old), sex (boys or girls),  
384 and culture (5 groups) nested within the full factorial model, with order of  
385 presentation (RAS, SRA or ASR) entered as a random intercept. The results of the  
386 best fitting model for each task are presented here, with details of model  
387 selection and the results of other models available in the supplementary  
388 materials. All significant culture effects were followed up with pairwise  
389 comparisons of least squares means estimates between all cultures, utilizing  
390 Bonferroni corrections for multiple comparisons.

### 391 *Innovation Rates.*

392 *Subtraction.* The best fitting model for innovation rates on the subtraction  
393 task contained significant fixed effects of age and culture, but no effect of gender  
394 and no interactions. The age effect indicated that children were innovating more  
395 on the subtraction task at older ages than younger ages,  $F(1, 397) = 21.36$ ,  $b =$   
396  $.34$ ,  $se = .07$ ,  $p = < .001$ , see Figure 3. The culture effect revealed that children  
397 from different groups varied in their innovation rates,  $F(4, 397) = 14.00$ ,  $p =$   
398  $< .001$ . Follow up comparisons revealed that the Western group innovated  
399 significantly more on the subtraction tool than any other group ( $bs$  ranged from  
400 1.37 to 3.09, all  $ps < .05$ , see supplementary materials). In addition, the Vanuatu  
401 township group was significantly poorer at innovating by subtraction than the  
402 Kgalagadi Bushmen group,  $b = -1.72$ ,  $se = .47$ ,  $p = .002$ .

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403            *Addition.* The best fitting model for innovation rates on the addition task  
404 contained significant fixed effects of age, culture and gender, but no interactions.  
405 The main effect of age,  $F(1, 397) = 50.45, b = .62, se = .09, p = <.001$   
406 demonstrated that children across all cultures innovated by addition at higher  
407 rates as they aged (see Figure 3). The culture effect demonstrated that there was  
408 variation in the levels of innovation across the 5 groups,  $F(4, 397) = 20.96, p =$   
409  $<.001$ . Follow up tests revealed that the Western group innovated significantly  
410 more compared to all other groups ( $bs$  ranged from 2.76 to 3.75, all  $ps < .001$ ),  
411 but that no other group significantly differed from each other on innovation rates  
412 (see supplementary materials for comparisons). A significant gender effect  
413 indicated that boys had higher rates of innovation by addition across all cultures  
414 than girls,  $F(1, 397) = 11.67, b = .99, se = .29, p = .001$ .

415            *Reshaping.* The best fitting model included significant fixed effects of age  
416 and culture, but no gender effect and no interactions. The age main effect  
417 revealed that all children improved in their ability to innovate by reshaping as  
418 they got older,  $F(1, 404) = 34.76, b = .47, se = .08, p < .001$ , refer Figure 3. The  
419 culture effect demonstrated variation in the rates of innovation across cultural  
420 group,  $F(4, 404) = 17.37, p < .001$ . Follow up comparisons found significant  
421 differences between Western groups compared to all groups ( $bs$  ranged from  
422 1.90 to 3.75, all  $ps < .001$ ) excepting the Platfontein Bushmen group ( $b = .74, se =$   
423  $.45, p = 1.000$ ). Thus, there was no evidence that the Platfontein Bushmen  
424 differed from the Western children in their capacity to innovate on the reshape  
425 task. In addition, the Platfontein Bushmen group innovated at significantly  
426 higher rates than the Vanuatu township group ( $b = -2.11, se = .52, p = .001$ ) and  
427 the Vanuatu village group ( $b = -2.41, se = .52, p < .001$ ).

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### 428 *Innovation Rates on First Insertion*

429           In general, the pattern of results for innovations occurring before  
430 inserting the tool into the tube reflected those for overall innovation rates (see  
431 supplemental materials for tables). Western children innovated significantly  
432 more on first insert than non-Western children (in 20-65% of instances for  
433 Western children across the three tasks and 0-21% for non-Western children; *bs*  
434 *ranged from .33 to .66, all  $ps \leq .002$ ; except on the subtract task where there*  
435 *were no group differences*), and older children more than younger children.  
436 Overall, a substantial number of children in all groups innovated before inserting  
437 the tool into the task, suggesting that haptic experience gained by applying the  
438 tool to the task may be necessary before many children recognize that the  
439 presenting tool is inadequate and go on to innovate its form.

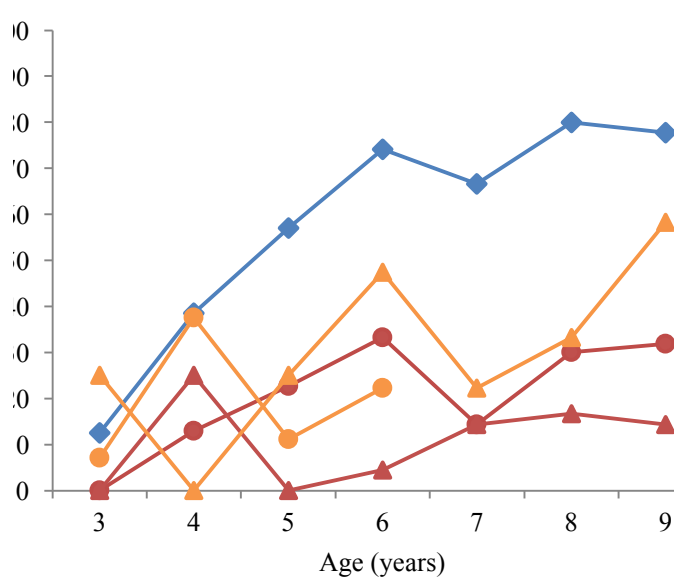
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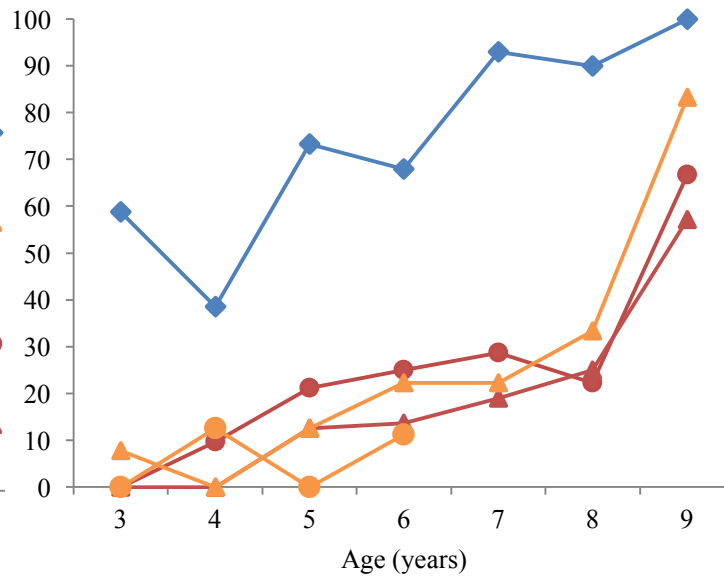
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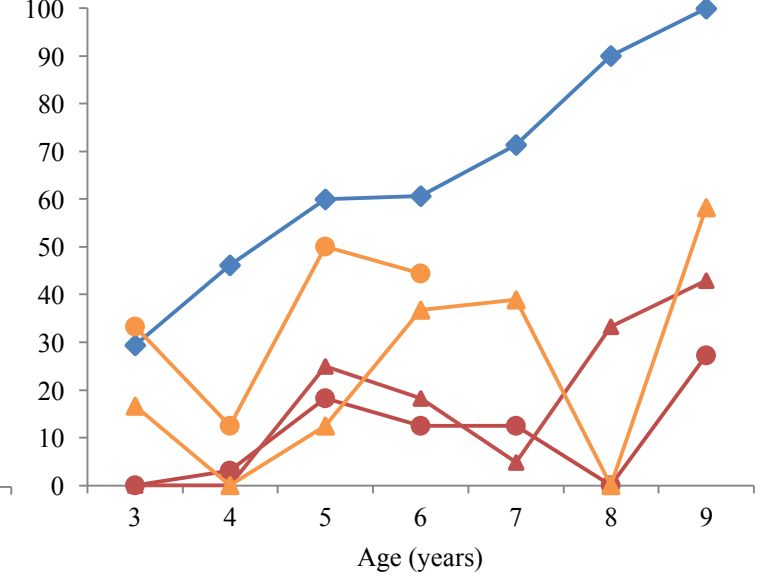
Subtract task



Add task



Reshape task



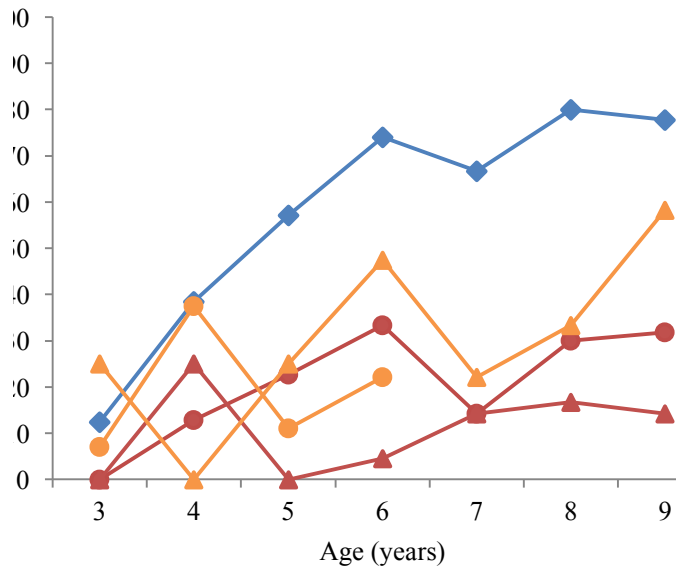
443

444 **Figure 3.** Percentage of children in each age group<sup>9</sup> across culture who innovated on the Subtract, Add and Reshape tasks.

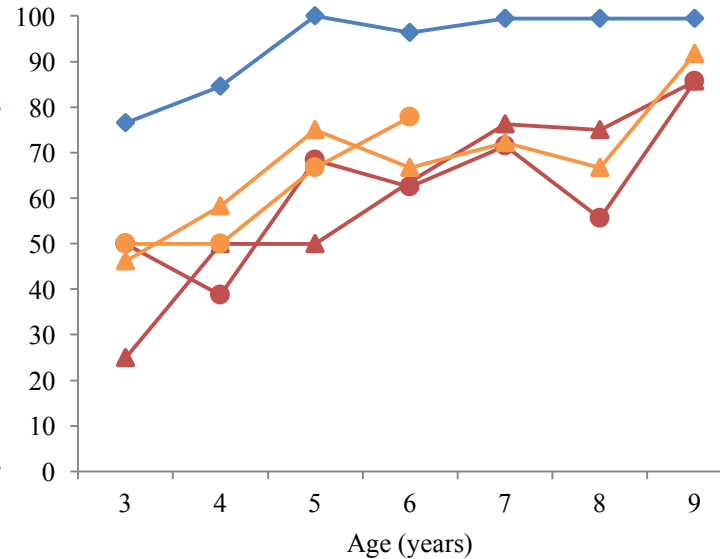
<sup>9</sup>The twelve children from the Ni-van township who did not have known ages are excluded from these graphs.

CHILDREN'S TOOL INNOVATION ACROSS CULTURE

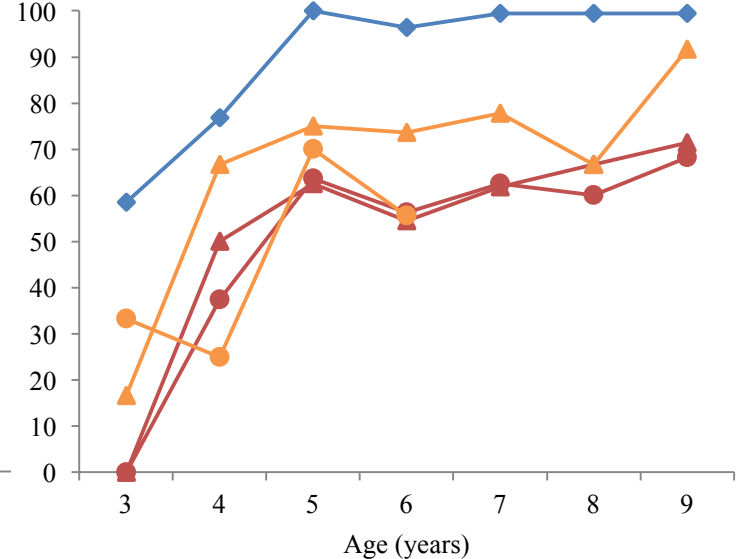
Subtract task



Add task



Reshape task



445

446 **Figure 4.** Percentage of children in each age group<sup>10</sup> across culture who successfully retrieved the sticker from the tube on the Subtract,

447 Add and Reshape tasks.

<sup>10</sup> The twelve children from the Ni-van township who did not have known ages are excluded from these graphs.



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448 *Success Rates.*

449           *Subtraction.* The best fitting model for success rates on the subtraction  
450 task using any strategy contained significant fixed effects of age and culture, but  
451 no effect of gender and no interactions. The age effect indicated that children  
452 were succeeding more on the subtraction task at older ages than younger ages,  $F$   
453  $(1, 397) = 19.45, b = .32, se = .07, p = < .001$ , see Figure 4. The culture effect  
454 revealed that children from different groups varied in their success rates,  $F$   $(4,$   
455  $397) = 13.97, p = <.001$ . Follow up comparisons revealed that the Western group  
456 succeeded significantly more often on the subtraction tool than any other group  
457 ( $bs$  ranged from 1.41 to 3.04, all  $ps < .01$ , see supplementary materials). In  
458 addition, the Vanuatu township group was significantly poorer at succeeding on  
459 the subtraction task than the Kgalagadi Bushmen group,  $b = -1.63, se = .46, p =$   
460  $.005$ .

461           *Addition.* The best fitting model for success rates using any strategy on the  
462 addition task contained significant fixed effects of age and culture, but no gender  
463 effect and no interactions. The main effect of age,  $F$   $(1, 398) = 25.86, b = .39, se =$   
464  $.08, p = <.001$ , indicated that older children were more successful than younger  
465 children at solving the task across all cultures (refer Figure 4). The main effect of  
466 culture demonstrated that children varied in their success rates across the 5  
467 groups,  $F$   $(4, 398) = 7.72. p = <.001$ . Follow up comparisons revealed that  
468 Western children were significantly more successful on the task than all other  
469 groups ( $bs$  ranged from 1.89 to 2.46, all  $ps < .004$ ,). However, there were no  
470 significant differences in the success rates of all other groups.

471           *Reshaping.* The best fitting model for success rates using any strategy on  
472 the reshape task contained significant fixed effects of age and culture, but no

473 gender effect and no interactions. The age effect demonstrated that children  
474 were more successful on the reshape task as they aged,  $F(1, 400) = 35.46$ ,  $b =$   
475  $.45$ ,  $se = .08$ ,  $p = <.001$ , see Figure 4. The culture effect again indicated variability  
476 in success rates amongst the five groups,  $F(4, 400) = 9.42$ ,  $p = <.001$ . Follow up  
477 comparisons revealed significant differences between the Western group  
478 compared to every other group (bs ranged from 1.62 to 2.40, all  $ps < .003$ ; see  
479 supplementary materials), with Western children being more successful on the  
480 task than all other children. There were no other significant group differences.

481 *Alternate Strategy Rates.*

482 A detailed description of children's alternate strategy rates is presented in  
483 the supplementary materials. Unlike for innovation, Western children did not  
484 employ an alternate strategy on the tasks significantly more than non-Western  
485 children. Rather, they used the alternative strategy at relatively similar rates to  
486 non-Western children on the reshape task, and significantly lower rates than  
487 non-Western children on the addition task. This suggests that the Western  
488 children's relative overall success compared to other groups was not due to  
489 higher adoptions of an alternate strategy, but due to higher employment of  
490 innovation techniques.

491 *Demonstration phases.*

492 Children who did not retrieve the sticker were presented with a Partial  
493 Demonstration and then if still failing, a Full Demonstration. Full results are  
494 presented in the Supplementary Material, but what these phases document is  
495 that the capacity<sup>11</sup> for making the target tools is within the motor action

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<sup>11</sup> When referring to capacity, we mean that within each of our tested age groups, some children were capable of performing the target tool manufacture and succeeding on the

496 capabilities of the children we tested –that is, the tasks were not physically  
497 beyond our participants once they were shown the actions by the experimenter.

498 **Discussion**

499 Our sociocultural environment influences the methods by which we  
500 innovate, and the tools we create (Ambrose, 2001; Foley & Lahr, 2003; Henrich &  
501 McElreath, 2003; Nielsen, in press). Yet research exploring differences in tool  
502 design across multiple cultural contexts is limited (Kline et al., 2018). We  
503 measured variability in children's tool innovation across five different cultural  
504 milieus using a range of manipulation actions. We predicted that children would  
505 become more skilled innovators as they aged. Consistent with previous research,  
506 older children within each culture were significantly more adept than younger  
507 children at innovating a new tool using subtraction, addition and reshaping to  
508 solve a task (S. R. Beck et al., 2011; S. R. Beck et al., 2014; Cutting, 2013; Cutting  
509 et al., 2014). By 7-9 years of age, the average child (summed across cultures)  
510 innovated in 26-74% of occurrences compared to the lower rates of 12-22% in  
511 the average 3-year-old; rates within the range of previous studies (S. R. Beck et  
512 al., 2011; Cutting, 2013; Neldner et al., 2017). We found higher performance  
513 rates in Western children than those reported in previous tests of tool  
514 innovation (rates from 12-59% for 3 year olds and 57-93% for 7 year olds),  
515 suggesting that simplifying task demands can facilitate children's tool innovation  
516 performance.

517 By monitoring innovations occurring not only before first insertion but  
518 also after, we were also able to detect innovations in an additional 83% of

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task after a demonstration. This suggests that it is within the cognitive and motor abilities of the children to perform this task at these ages once shown the appropriate action.

519 children (averaged across cultures and tasks) that would not have been  
520 considered on previous tasks. This suggests that a majority of children only  
521 innovate following haptic experience and exploration of the task materials  
522 (Lancy, 2017). Future tasks should incorporate exploration time prior to testing  
523 in order to allow children opportunity to investigate the affordances of the task.

524         Our findings support the notion that young children, while being very  
525 skilled imitators and avid social learners (Legare & Nielsen, 2015), are less likely  
526 to innovate (S. R. Beck et al., 2012; Cutting, 2013). It may be more crucial to  
527 adopt normative uses of tools when young, to ensure social cohesion and a rapid  
528 transmission of skills. Only in the later years of childhood might children begin to  
529 solve problems independently and build on existing cultural knowledge (Locke &  
530 Bogin, 2006; Riede et al., 2018). The parallel developmental trajectories we  
531 observed across 5 distinct groups and 3 different manipulation actions suggest  
532 that children's innovation improvement across age may be a universal  
533 phenomenon.

534         We also found evidence for cultural variation in children's tool innovation  
535 proclivities on these tasks. While performance across the non-Westernized  
536 small-scale society groups was, in general, similar, the performance of children  
537 from a Westernized city was considerably higher (with one notable exception  
538 when comparing with Platfontein children in the Reshape condition, who  
539 demonstrated similar proficiency to Western children). Our findings highlight  
540 the importance of collecting measures from multiple cultural samples before  
541 inferring generalizability of a trait (Nielsen & Haun, 2016; Nielsen, Haun,  
542 Kärtner, & Legare, 2017). Had we examined our Western sample only, we might  
543 have made conclusions misrepresenting the breadth of variability in innovation

544 performance in our extended sample. Instead, we found that children across our  
545 sample often utilized the tools in alternate ways (using force or multi-tool use) in  
546 order to retrieve the sticker. This suggests that different elements of the tool and  
547 task were salient to the children in each group, generating different behavioral  
548 approaches to solving it. Further, it highlights the flexibility inherent in  
549 children's tool use – several approaches may be used within even a simple task  
550 to achieve the same goal.

551         While the purpose of the current investigation was to track variability in  
552 innovation proclivity across culture, the cultural factors driving our observed  
553 differences, and their unique level of contribution, are still unclear. These  
554 children varied on numerous sociocultural variables, including their level of  
555 exposure to and interaction with family tools, familiarity with testing contexts  
556 and materials, access to schooling, and exposure to white people, none of which  
557 were directly measured. Any or all of these factors may play a role in shaping a  
558 child's understanding of tools and affect the way they interact with them on  
559 experimental tasks. What we can surmise, however, is that irrespective of the  
560 driving mechanisms or the specific combination of them, the social world in  
561 which a child develops has a direct influence on how they perceive a tool-related  
562 problem, and the strategies they devise to solve it. A valuable goal for future  
563 research then would be to isolate and quantify the role of such variables within  
564 these tasks.

565         For example, it is likely that differences in our samples' exposure to novel  
566 artifacts through formal education influenced their approaches to and successes  
567 in tool innovation. The way children play and explore objects is heavily  
568 influenced by prior experience and social exposure (Bakeman et al., 1990;

569 Bjorklund & Gardiner, 2011; Lancy, 2017; Nagell, Olguin, & Tomasello, 1993;  
570 Tomasello, Savage-Rumbaugh, & Kruger, 1993; Williamson, Meltzoff, &  
571 Markman, 2008). Children that engage with a large diversity of tool artifacts,  
572 such as is typical in Western cultures, display more divergent thinking skills  
573 (Riede et al., 2018). Western children are much more likely to be familiar with  
574 toys designed for constructive purposes, such as Lego or blocks (Bjorklund &  
575 Gardiner, 2011), and receive more parental facilitation during object play than  
576 children from small-scale societies (Bakeman et al., 1990; although see Little et  
577 al., 2016 for differences seen in modality type but not overall facilitation). These  
578 factors might contribute to their relative aptitude in innovating tools on these  
579 particular tool innovation tasks and detecting affordances in the materials faster  
580 (ie. before inserting the tool into the tube). This pattern extends previous  
581 research implicating formal education as a contributing factor in the onset of  
582 theory of mind and mental forecasting in children (Dixson et al., 2017; Redshaw  
583 et al., 2018) to include tool innovation onset. However, despite variation in the  
584 level of formal schooling available between our Kalahari bushmen and Ni-Van  
585 groups, in general their innovation rates were similar, suggesting that education  
586 alone cannot fully account for our observed differences between cultural groups.

587         Unfortunately, we were unable to make direct comparisons on tool  
588 innovation performance between the tasks and therefore could not determine  
589 whether children displayed superior skill in one action domain over another.  
590 Research from nonhuman animals suggests a hierarchy of action complexity  
591 might exist, as detachment is observed far more commonly than addition or  
592 reshaping (B. B. Beck, 1980; Kacelnik et al., 2006; E. Visalberghi, Frigaszy, &  
593 Savagerumbaugh, 1995; Elisabetta Visalberghi & Trinca, 1989), and chimpanzees

594 are better at subtraction than addition when constructing tools (Bania et al.,  
595 2009). However, the one reported account of action complexity in children failed  
596 to detect a hierarchy like this (Cutting, 2013). Alternatively, it is possible that  
597 children might develop aptitudes for certain actions in some cultures - the  
598 Platfontein Bushmen children demonstrated particular skill in reshaping  
599 techniques relative to other non-Western groups and other innovation actions,  
600 suggesting that their cultural environment enabled them to become particularly  
601 skilled within this domain. Further constraining our task to only allow  
602 innovation solutions, and comparing performance between each action to see if a  
603 hierarchy of complexity exists in children would be extremely valuable as a  
604 pursuit for future research. Further, it is possible that doing so might see  
605 children's innovation rates increase by making innovation necessary for success.

606         Our unexpected gender effects revealed that boys performed significantly  
607 more additive innovations than girls in each group, and that they innovated the  
608 correct tool before insertion more often than girls on both the add and subtract  
609 tasks. It is possible that boys receive more exposure to models using and  
610 combining tools from a young age than girls across cultures, although we know  
611 of no research to suggest this is the case. There is however, evidence that boys  
612 tend to build more structures than girls (Caldera et al., 1999), and will engage in  
613 more object-related play than girls in comparison to other forms of play in  
614 Western contexts (such as social play; Bjorklund & Gardiner, 2011). This  
615 suggests that boys might be more inclined to engage with physical tools from an  
616 early age (Bjorklund & Gardiner, 2011; Bornstein, Haynes, O'Reilly, & Painter,  
617 1996; Gredlein & Bjorklund, 2005), which might allow them to learn to detect  
618 object-related affordances faster. Future investigations could examine the types

619 of tool-using actions and amount of tools used by adults in the presence of girls  
620 and boys across multiple cultural ethnographies to further shed light on this  
621 question.

622         Finally, our findings raise an important issue regarding the ecological  
623 validity of the methodologies employed in cross-cultural research. Tasks  
624 developed in one cultural context may not easily or equally translate to another  
625 (Kline et al., 2018). For example, Ni-Van children routinely create tools and solve  
626 practical problems using palm leaves and vines rather than the plastic and  
627 rubber dowels used in our experiment. Their tool making consists of the weaving  
628 of baskets and grass skirts for girls or thatching of roofs for boys. Unlike in  
629 Western cultures, there is little pedagogy involved in the transfer of these new  
630 skills to children, instead younger siblings watch older siblings or adults  
631 performing these actions and imitate them (Clegg & Legare, 2016; Lancy, 2017).  
632 Further, in small-scale societies it is customary to defer to authority figures and  
633 to not voice opinions or divert from established social roles in their presence  
634 (Clegg et al., 2017; Wang, Devine, Wong, & Hughes, 2016). These variables in  
635 combination might have suppressed Ni-Van children's innovative action on these  
636 elected tasks. Had they been allowed to explore the task in front of a trained age-  
637 matched peer rather than an experimenter and translator, or if natural materials  
638 were instead provided, innovation rates and explorative action might have  
639 increased in Ni-Van groups. The implementation of Westernized tasks to other  
640 contexts must be done with caution and a preparedness to acknowledge  
641 potential confounding variables to ensure such investigations remain valuable  
642 (Kline et al., 2018). Future studies would benefit from incorporating



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643 ethnographic information within the design process to ensure tasks are as  
644 comparable as possible across elected study sites.

645         Tool innovation certainly appears to be difficult for young children.  
646 However, the results of the current study demonstrate that, when mapping  
647 across distinct cultures and several action types, children's innovation skills  
648 reliably improve with age. This pattern of relatively late, but predictable  
649 development stands in stark contrast to another remarkable human capacity –  
650 imitation – which children universally acquire as toddlers and preschoolers  
651 (Legare & Nielsen, 2015; Tomasello, 2016). A primary payoff of an extended  
652 childhood in humans might then be that it allows children to transition from  
653 rampant copiers to resourceful innovators, and in doing so allows them to  
654 become active perpetuators in advancing cultural knowledge for their  
655 community.

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## References

- 657 Ambrose, S. H. (2001). Paleolithic technology and human evolution. *Science*,  
658 291(5509), 1748-1753.
- 659 Bakeman, R., Adamson, L. B., Konner, M. J., & Barr, R. G. (1990). !Kung Infancy:  
660 The Social Context of Object Exploration. *Child Development*, 61(3), 794-  
661 809. doi:10.2307/1130964
- 662 Bania, A. E., Harris, S., Kinsley, H. R., & Boysen, S. T. (2009). Constructive and  
663 deconstructive tool modification by chimpanzees (*Pan troglodytes*).  
664 *Animal Cognition*, 12(1), 85-95. doi:10.1007/s10071-008-0173-0
- 665 Beck, B. B. (1980). *Animal tool behavior*: Garland STPM Pub.
- 666 Beck, S. R., Apperly, I. A., Chappell, J., Guthrie, C., & Cutting, N. (2011). Making  
667 tools isn't child's play. *Cognition*, 119(2), 301-306.  
668 doi:10.1016/j.cognition.2011.01.003
- 669 Beck, S. R., Chappell, J., Apperly, I. A., & Cutting, N. (2012). Tool innovation may  
670 be a critical limiting step for the establishment of a rich tool-using culture:  
671 A perspective from child development. *Behavioral and Brain Sciences*,  
672 35(4), 220-+. doi:10.1017/S0140525x11001877
- 673 Beck, S. R., Cutting, N., Apperly, I. A., Demery, Z., Iliffe, L., Rishi, S., & Chappell, J.  
674 (2014). Is tool-making knowledge robust over time and across problems?  
675 *Frontiers in Psychology*, 5. doi:ARTN 1395  
676 10.3389/fpsyg.2014.01395
- 677 Beck, S. R., Williams, C., Cutting, N., Apperly, I. A., & Chappell, J. (2016). Individual  
678 differences in children's innovative problem-solving are not predicted by  
679 divergent thinking or executive functions. *Philosophical Transactions of*

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 680            *the Royal Society of London B: Biological Sciences*, 371(1690).  
681            doi:10.1098/rstb.2015.0190
- 682    Biro, D., Sousa, C., & Matsuzawa, T. (2006). Ontogeny and cultural propagation of  
683            tool use by wild chimpanzees at Bossou, Guinea: Case studies in nut  
684            cracking and leaf folding. *Cognitive development in chimpanzees*, ed. T.  
685            Matsuzawa, M. Tomonaga & M. Tanaka, 476-508.
- 686    Bjorklund, D. F., & Gardiner, A. K. (2011). Object play and tool use:  
687            Developmental and evolutionary perspectives. In A. D. Pellegrini (Ed.),  
688            *The Oxford handbook of the development of play*. (pp. 153-171). USA:  
689            Oxford University Press.
- 690    Boesch, C., & Boesch, H. (1983). Optimisation of nut-cracking with natural  
691            hammers by wild chimpanzees. *Behaviour*, 265-288.
- 692    Borgerhoff Mulder, M., & Schacht, R. (2012). Human behavioural ecology. *eLS*.
- 693    Bornstein, M. H., Haynes, O. M., O'Reilly, A. W., & Painter, K. M. (1996). Solitary  
694            and collaborative pretense play in early childhood: Sources of individual  
695            variation in the development of representational competence. *Child*  
696            *Development*, 67(6), 2910-2929.
- 697    Brown, A. L. (1990). Domain-Specific Principles Affect Learning and Transfer in  
698            Children. *Cognitive Science*, 14(1), 107-133. doi:DOI  
699            10.1207/s15516709cog1401\_6
- 700    Caldera, Y. M., Mc Culp, A., O'Brien, M., Truglio, R. T., Alvarez, M., & Huston, A. C.  
701            (1999). Children's play preferences, construction play with blocks, and  
702            visual-spatial skills: Are they related? *International Journal of Behavioral*  
703            *Development*, 23(4), 855-872.

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 704 Casler, K., & Kelemen, D. (2005). Young children's rapid learning about artifacts.  
705 *Developmental Science*, 8(6), 472-480.
- 706 Chappell, J., Cutting, N., Apperly, I. A., & Beck, S. R. (2013). The development of  
707 tool manufacture in humans: what helps young children make innovative  
708 tools? *Philosophical Transactions of the Royal Society B-Biological Sciences*,  
709 368(1630). doi:ARTN 20120409  
710 10.1098/rstb.2012.0409
- 711 Chen, Z., Siegler, R. S., & Daehler, M. W. (2000). Across the Great Divide: Bridging  
712 the Gap between Understanding of Toddlers' and Older Children's  
713 Thinking. *Monographs of the Society for Research in Child Development*,  
714 65(2), i-105.
- 715 Clegg, J. M., & Legare, C. H. (2016). Instrumental and conventional interpretations  
716 of behavior are associated with distinct outcomes in early childhood. *Child*  
717 *Development*, 87(2), 527-542.
- 718 Clegg, J. M., Wen, N. J., & Legare, C. H. (2017). Is non-conformity WEIRD? Cultural  
719 variation in adults' beliefs about children's competency and conformity.  
720 *Journal of Experimental Psychology: General*, 146(3), 428.
- 721 Connolly, K., & Dalgleish, M. (1989). The emergence of a tool-using skill in  
722 infancy. *Developmental Psychology*, 25(6), 894-912. doi:10.1037/0012-  
723 1649.25.6.894
- 724 Costello, M. (1987). *Tool use and manufacture in manipulanda-deprived capuchins*  
725 *(Cebus apella): Ontogenetic and phylogenetic issues*. (12, 3). American  
726 Journal of Primatology.
- 727 Cutting, N. (2013). *Children's tool making: from innovation to manufacture*.  
728 University of Birmingham.

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 729 Cutting, N., Apperly, I. A., & Beck, S. R. (2011). Why do children lack the flexibility  
730 to innovate tools? *Journal of Experimental Child Psychology*, *109*(4), 497-  
731 511. doi:10.1016/j.jecp.2011.02.012
- 732 Cutting, N., Apperly, I. A., Chappell, J., & Beck, S. R. (2014). The puzzling difficulty  
733 of tool innovation: Why can't children piece their knowledge together?  
734 *Journal of Experimental Child Psychology*, *125*, 110-117.  
735 doi:10.1016/j.jecp.2013.11.010
- 736 Foley, R., & Lahr, M. M. (2003). On stony ground: lithic technology, human  
737 evolution, and the emergence of culture. *Evolutionary Anthropology:*  
738 *Issues, News, and Reviews*, *12*(3), 109-122.
- 739 Gredlein, J. M., & Bjorklund, D. F. (2005). Sex differences in young children's use  
740 of tools in a problem-solving task. *Human Nature*, *16*(2), 211-232.
- 741 Harkness, S., Blom, M., Oliva, A., Moscardino, U., Zylicz, P. O., Bermudez, M. R., . . .  
742 Super, C. M. (2007). Teachers' ethnotheories of the 'ideal student' in five  
743 western cultures. *Comparative Education*, *43*(1), 113-135.
- 744 Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the  
745 world? *Behavioral and Brain Sciences*, *33*(2-3), 61-83.
- 746 Henrich, J., & McElreath, R. (2003). The evolution of cultural evolution.  
747 *Evolutionary Anthropology: Issues, News, and Reviews*, *12*(3), 123-135.
- 748 Hewlett, B. S., Fouts, H. N., Boyette, A. H., & Hewlett, B. L. (2011). Social learning  
749 among Congo Basin hunter-gatherers. *Philosophical Transactions of the*  
750 *Royal Society of London B: Biological Sciences*, *366*(1567), 1168-1178.
- 751 Hodder, I., & Hutson, S. (2003). *Reading the past: current approaches to*  
752 *interpretation in archaeology*: Cambridge University Press.

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 753 Kacelnik, A., Chappell, J., Weir, A. A. S., & Kenward, B. (2006). Cognitive  
754 adaptations for tool-related behaviour in New Caledonian Crows. In E. A.  
755 Wasserman & T. R. Zentall (Eds.), *Comparative cognition: experimental*  
756 *explorations of animal intelligence* (pp. 515-528). Oxford: Oxford  
757 University Press.
- 758 Kleinbooi, K. (2007). *Schmidtsdrift community land claim*: Programme for Land  
759 and Agrarian Studies.
- 760 Kline, M. A., Shamsudheen, R., & Broesch, T. (2018). Variation is the universal:  
761 making cultural evolution work in developmental psychology.  
762 *Philosophical Transactions of the Royal Society B: Biological Sciences*,  
763 373(1743).
- 764 Köhler, W. (1917). *Intelligenzprüfungen an anthropoiden. 1*: Königl. akademie der  
765 wissenschaften.
- 766 Köhler, W. (1925). *The Mentality of Apes*: London: K. Paul, Trench, Trubner.
- 767 Lancy, D. F. (2017). Homo Faber Juvenalis: A Multidisciplinary Survey of Children  
768 as Tool Makers/Users. *Childhood in the Past*, 10(1), 72-90.  
769 doi:10.1080/17585716.2017.1316010
- 770 Legare, C. H., & Nielsen, M. (2015). Imitation and Innovation: The Dual Engines of  
771 Cultural Learning. *Trends Cogn Sci*, 19(11), 688-699.  
772 doi:10.1016/j.tics.2015.08.005
- 773 Lethmate, J. (1978). An investigation of "prestipulated" transactions with a  
774 young orangutan. *Primates*.
- 775 Little, E. E., Carver, L. J., & Legare, C. H. (2016). Cultural Variation in Triadic  
776 Infant–Caregiver Object Exploration. *Child Development*.

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 777 Locke, J. L., & Bogin, B. (2006). Language and life history: A new perspective on  
778 the development and evolution of human language. *Behavioral and Brain*  
779 *Sciences*, 29(3), 259-280.
- 780 McGrew, W. C. (1974). Tool use by wild chimpanzees in feeding upon driver ants.  
781 *Journal of Human Evolution*, 3(6), 501-508.
- 782 McGuigan, N., & Whiten, A. (2009). Emulation and "overemulation" in the social  
783 learning of causally opaque versus causally transparent tool use by 23-  
784 and 30-month-olds. *Journal of Experimental Child Psychology*, 104(4), 367-  
785 381. doi:10.1016/j.jecp.2009.07.001
- 786 Mesoudi, A., Chang, L., Murray, K., & Lu, H. J. (2015). Higher frequency of social  
787 learning in China than in the West shows cultural variation in the  
788 dynamics of cultural evolution. *Proceedings of the Royal Society of London*  
789 *B: Biological Sciences*, 282(1798), 20142209.
- 790 Nagell, K., Olguin, R. S., & Tomasello, M. (1993). Processes of social learning in the  
791 tool use of chimpanzees (*Pan troglodytes*) and human children (*Homo*  
792 *sapiens*). *Journal of Comparative Psychology*, 107(2), 174.
- 793 Neldner, K., Mushin, I., & Nielsen, M. (2017). Young children's tool innovation  
794 across culture: Affordance visibility matters. *Cognition*, 168, 335-343.
- 795 Nielsen, M. (in press). The social glue of cumulative culture and ritual behavior.  
796 *Child Development Perspectives*. doi:10.1111/cdep.12297
- 797 Nielsen, M., & Haun, D. B. M. (2016). Why developmental psychology is  
798 incomplete without comparative and cross-cultural perspectives.  
799 *Philosophical Transactions of the Royal Society of London B: Biological*  
800 *Sciences*, 371(1686). doi:10.1098/rstb.2015.0071

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 801 Nielsen, M., Haun, D. B. M., Kärtner, J., & Legare, C. H. (2017). The persistent  
802 sampling bias in developmental psychology: A call to action. *Journal of*  
803 *Experimental Child Psychology*, 162, 31-38.
- 804 Nielsen, M., Tomaselli, K., Mushin, I., & Whiten, A. (2014). Exploring tool  
805 innovation: A comparison of Western and Bushman children. *Journal of*  
806 *Experimental Child Psychology*, 126, 384-394.  
807 doi:10.1016/j.jecp.2014.05.008
- 808 Pruett, J. D., & Bertolani, P. (2007). Savanna chimpanzees, *Pan troglodytes verus*,  
809 hunt with tools. *Current Biology*, 17(5), 412-417.
- 810 Reindl, E., Beck, S. R., Apperly, I. A., & Tennie, C. (2016). Young children  
811 spontaneously invent wild great apes' tool-use behaviours. *Proceedings of*  
812 *the Royal Society of London B: Biological Sciences*, 283(1825).  
813 doi:10.1098/rspb.2015.2402
- 814 Riede, F., Johannsen, N. N., Högberg, A., Nowell, A., & Lombard, M. (2018). The  
815 role of play objects and object play in human cognitive evolution and  
816 innovation. *Evolutionary Anthropology: Issues, News, and Reviews*, 27(1),  
817 46-59. doi:doi:10.1002/evan.21555
- 818 Sanz, C. M., & Morgan, D. B. (2007). Chimpanzee tool technology in the Goualougo  
819 Triangle, Republic of Congo. *Journal of Human Evolution*, 52(4), 420-433.
- 820 Schlereth, T. J. (1985). *Material culture: A research guide*: University Press of  
821 Kansas Lawrence, KS.
- 822 Shumaker, R. W., Walkup, K. R., & Beck, B. B. (2011). *Animal tool behavior: the use*  
823 *and manufacture of tools by animals*: JHU Press.



## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 824 Stoinski, T. S., & Beck, B. B. (2001). Spontaneous tool use in captive, free-ranging  
825 golden lion tamarins (*Leontopithecus rosalia rosalia*). *Primates*, 42(4),  
826 319-326.
- 827 Suizzo, M.-A. (2007). Parents' goals and values for children: Dimensions of  
828 independence and interdependence across four US ethnic groups. *Journal*  
829 *of Cross-Cultural Psychology*, 38(4), 506-530.
- 830 Tobin, J., Hsueh, Y., & Karasawa, M. (2009). *Preschool in three cultures revisited:*  
831 *China, Japan, and the United States*: University of Chicago Press.
- 832 Tomaselli, K. G. (2005). *Where global contradictions are sharpest: Research stories*  
833 *from the Kalahari* (Vol. 1): Rozenberg Publishers.
- 834 Tomasello, M. (2016). The ontogeny of cultural learning. *Current Opinion in*  
835 *Psychology*, 8, 1-4. doi:<https://doi.org/10.1016/j.copsyc.2015.09.008>
- 836 Tomasello, M., Savage-Rumbaugh, S., & Kruger, A. C. (1993). Imitative learning of  
837 actions on objects by children, chimpanzees, and enculturated  
838 chimpanzees. *Child Development*, 64(6), 1688-1705.
- 839 van Schaik, C. P., Ancrenaz, M., Borgen, G., Galdikas, B., Knott, C. D., Singleton, I., . .  
840 . Merrill, M. Y. (2003). Orangutan cultures and the evolution of material  
841 culture. *Science*, 299(5603), 102-105.
- 842 van Schaik, C. P., Ancrenaz, R., Djojoasmoro, C. D., Knott, H. C., Morrogh-Bernard,  
843 N., Odom, S. S., . . . van Noordwijk, M. A. (2009). Orangutan cultures  
844 revisited. In S. A. Wich, S. S. U. Atmoko, T. M. Setia, & C. P. Van Schaik  
845 (Eds.), *Orangutans: geographic variation in behavioral ecology and*  
846 *conservation* (pp. 299-309): OUP Oxford.
- 847 Visalberghi, E., Fragaszy, D. M., & Savagerumbaugh, S. (1995). Performance in a  
848 Tool-Using Task by Common Chimpanzees (*Pan-Troglodytes*), Bonobos

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 849 (Pan-Paniscus), an Orangutan (Pongo-Pygmaeus), and Capuchin Monkeys  
850 (Cebus-Apella). *Journal of Comparative Psychology*, 109(1), 52-60. doi:Doi  
851 10.1037//0735-7036.109.1.52
- 852 Visalberghi, E., & Trinca, L. (1989). Tool use in capuchin monkeys: Distinguishing  
853 between performing and understanding. *Primates*, 30(4), 511-521.
- 854 Wang, Z., Devine, R. T., Wong, K. K., & Hughes, C. (2016). Theory of mind and  
855 executive function during middle childhood across cultures. *Journal of*  
856 *Experimental Child Psychology*, 149, 6-22.
- 857 Wen, N. J., Clegg, J. M., & Legare, C. H. (2017). Smart Conformists: Children and  
858 Adolescents Associate Conformity With Intelligence Across Cultures. *Child*  
859 *Development*.
- 860 Westergaard, G. C., & Fragaszy, D. M. (1987a). The manufacture and use of tools  
861 by capuchin monkeys (*Cebus apella*). *Journal of Comparative Psychology*,  
862 101(2), 159.
- 863 Westergaard, G. C., & Fragaszy, D. M. (1987b). Self-treatment of wounds by a  
864 capuchin monkey (*Cebus apella*). *Human Evolution*, 2(6), 557-562.
- 865 Whiten, A., Goodall, J., McGrew, W. C., Nishida, T., Reynolds, V., Sugiyama, Y., . . .  
866 Boesch, C. (1999). Cultures in chimpanzees. *Nature*, 399(6737), 682-685.  
867 doi:Doi 10.1038/21415
- 868 Whiten, A., Goodall, J., McGrew, W. C., Nishida, T., Reynolds, V., Sugiyama, Y., . . .  
869 Boesch, C. (2001). Charting cultural variation in chimpanzees. *Behaviour*,  
870 138(11), 1481-1516.
- 871 Williamson, R. A., Meltzoff, A. N., & Markman, E. M. (2008). Prior experiences and  
872 perceived efficacy influence 3-year-olds' imitation. *Developmental*  
873 *Psychology*, 44(1), 275.

## CHILDREN'S TOOL INNOVATION ACROSS CULTURE

- 874 Winterhalder, B., & Kennett, D. J. (2006). Behavioral ecology and the transition  
875 from hunting and gathering to agriculture. *Behavioral ecology and the*  
876 *transition to agriculture*, 1-21.