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Why Do Children Lack Flexibility When Making Tools? The Role of Social Learning in Innovation

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The capacity of humans to manufacture and use tools has evolved far beyond that seen in any other species (Boyd, Richerson, and Henrich 2011). This is thought to be due to our propensity for cumulative culture (Boyd and Richerson 1996), where new techniques are copied throughout the social group and then improved on in a ratchet-like effect (Tomasello 1999; Tomasello, Kruger, and Ratner 1993). Cumulative culture involves two factors termed "dual engines" (Legare and Nielsen 2015)—imitation and innovation. The cumulative culture literature has predominantly focused on imitation, how techniques are transmitted through groups through social learning, with children demonstrating faithful replication of techniques from a young age. Only more recently have researchers focused efforts toward measuring propensity for the second engine—innovation. This chapter focuses on tool-innovation, which is defined as the design and manufacture of new tools or the modification of existing tools to solve a problem (Cutting et al. 2014).

In contrast to human disposition for social learning, research with children has demonstrated that capacity for innovation is somewhat weaker. However, studies into children's innovation have predominantly used paradigms based on Ramsey, Bastian, and van Schaik's (2007) where innovation is defined as an individual, asocial process devoid of external social influences. The difficulty children demonstrate in these individual problem-solving tasks may mask their ability for more socially mediated innovations (Rawlings and Legare 2020). This chapter will discuss how tool-innovation would be better categorized as a socially embedded process, where socially acquired information affects the innovation of new tools and then these innovations are transmitted back to the social group. In such a socially interconnected society, I would argue that all tool-innovation contains some degree of social influence and can never be truly asocial. Social influence could be by direct communication and teaching or by indirect social influences such as materials clearly having been made by other individuals. To date, most tool-innovation paradigms that have been used are too close to the asocial end of an asocial-to-social continuum.

Cumulative culture demonstrates the need for both technical rigidity and technical flexibility for different processes. Rigidity is required in social learning to ensure faithful transmission of information. In contrast, innovations require technical flexibility. Individual innovations can occur through flexibility in behavioral repertoires (i.e., the ability to add or remove behaviors) or flexibility in the behaviors themselves, evidenced by modifications within those behaviors. Following an overview of cumulative culture, how innovations occur, and what studying children can tell us about the development of techniques, this chapter will predominantly focus on technical flexibility in children's innovations. An overview of children's capacity for asocial and socially mediated tool-innovation will assess flexibility in children's behavioral repertoires. This will be followed by analysis of flexibility in children's tool behaviors once learned. Throughout this chapter, I will argue that the relatively new field of children's tool-innovation has focused too heavily on children's ability to innovate in asocial contexts, which may be masking capacity for technical flexibility.

How Do Tool Techniques Develop? The Role of Cumulative Culture

There is no doubt that the human species has been exceptionally successful in creating and developing an abundance of tools to aid our needs in nearly all aspects of our lives. It is difficult to imagine how our lives are not enhanced by the presence of simple tools such as cutlery and pencils to much more complex tools such as smartphones and computers. That is not to mention the hugely complex tools outside most of our daily lives such as spacecraft and hadron colliders. While we are not the only species to use tools (see Shumaker, Walkup, and Beck 2011 for a catalog of animal tool behavior), humans are unique in the sheer number and complexity of tools that we use. Our nearest relative, the chimpanzee, with which we shared a common ancestor roughly 7 million years ago, uses an array of tools including sticks for termite-fishing (Koops 2020) and nut-cracking (Boesch et al. 2019), yet they have failed to progress beyond this comparatively rudimentary set of tools. So, how have humans managed to achieve such a sophisticated technological toolkit?

Human technological success, it is suggested, is due to our capacity for cumulative technological culture: the gradual progression of techniques and tools, building on what has come before by enhancing its complexity and efficiency (Dean et al. 2014; Legare and Nielsen 2015). Over generations, these progressions accumulate to create a technique or tool that is too complex to have been invented independently by one individual (Boyd and Richerson 1996; Tennie, Call, and Tomasello 2009; Tomasello, Kruger, and Ratner 1993). Cumulative technological culture is proposed to be driven by the dual engines (Legare and Nielsen 2015) of imitation and innovation. For cumulative evolution to occur, a group must produce modifications to existing techniques, and these modifications must then be transmitted throughout the group (Charbonneau 2015). Most theories suggest that human uniqueness for cumulative technological culture is the result of our capacity for high-fidelity social learning—active teaching and faithful imitation. As such, most research has focused on the social transmission aspect of culture, with a wealth of research demonstrating humans to be faithful social learners, copying to a high fidelity from a young age. By age 2, children will over-imitate, copying causally irrelevant actions, a phenomenon that appears to be unique to humans and that clearly showcases our propensity for faithful transmission (see Hoehl et al. 2019 for a review).

While these lines of research have focused on important questions surrounding the uniqueness of human cumulative culture and its evolutionary origins, despite being recognized as essential, the second component of cumulative culture—innovation—has been somewhat neglected. Faithful transmission of techniques may be the strong driving force behind cumulative evolution, but without deviations from faithful copying, new behaviors and products would not emerge (Charbonneau 2015; Kendal, Giraldeau, and Laland 2009). The lack of focus on innovations has led to the presumption that innovation rates and ability are comparable between human and nonhuman species (Dean et al. 2014; Tennie, Call, and Tomasello 2009; Tomasello, Kruger, and Ratner 1993); however, there is little evidence to support this claim.

How Do Innovations Occur?

There are three ways that new innovations can occur: incremental improvements, serendipity, and recombination (see Muthukrishna and Henrich [2016] for a more in-depth overview, including real-world examples for each type of innovation). Innovations are commonly the product of incremental improvements of what has come before. These innovations are also referred to as modifications and must retain some aspects of their ancestor but also differ in some respect (Charbonneau 2015). These are the type of innovation that fits most neatly within the cumulative culture narrative and explains gradual advances in culture that occur over generations but often ultimately lead to a product that is unrecognizable from its beginnings.

Serendipitous innovations are nondirected and can occur because of mistakes that are made by individuals. These mistakes lead to the discovery of new techniques or products and can be made during individual learning or when attempting to replicate a technique through social learning (Henrich 2004; Powell, Shennan, and Thomas 2009). This type of innovation that is the result of good fortune rather than brought about by design often creates larger, more step-change innovations.

Finally, innovations can be the result of recombining existing knowledge or techniques in new ways. This can often give the impression of impressive step-change innovations but more accurately involves the innovator being exposed to several individual ideas that happen to come together in time (Charbonneau 2016). As such, recombination innovations in history have often been proposed by several individuals at around the same time because of similar exposure to information and ideas; an example is Darwin and Wallace's theory of evolution (Muthukrishna and Henrich 2016).

A number of disciplines have tracked and documented innovations throughout history. Developmental psychology is one approach that has been taken to investigate the potential origins of innovative ability in humans.

Why Study Innovation in Children?

The purpose of this book is to bring together ideas from different disciplines to approach the topic of flexibility and rigidity in the use and transmission of techniques. This brings the question of how children fit into this narrative. Do children produce long-lasting traditions that are transmitted within and across generations? Is there an active role for children in cumulative cultural evolution? And, as is the focus of this chapter, what is children's role in the innovation of new techniques? In this section, I will discuss ways that research with children can fit into this narrative and explain why my work on tool-innovation has taken a developmental perspective.

There are some traditions that spread and evolve that are ubiquitous with children. Playing games is one such example. Games are not restricted to any one age group; however, when we think of playing games, children are usually the first group of people that come to mind. Although this topic is difficult to study because of gaps in the historical record, Olivier Morin (2015) has systematically explored 103 French games documented by Rabelais that appeared between the Middle Ages and the early 1900s. Although the origins of some games are difficult to ascertain (i.e., they may have been designed and introduced to children by adults), Morin concludes that children ensure the longevity of games and play an active role in their development. Morin points out that what is most impressive about the transmission of children's games is that diffusion between children is horizontal. Horizontal transmission should be weaker than the more traditional vertical transmission from generation to generation, yet children's games appear to be just as long-lived as adult and cross-generational games. Thus, in the domain of games, children are strong players with the ability to produce and maintain long-lasting traditions.

Moving back to the focus of this chapter, technological culture, and thinking about recent advances in this domain, children are not likely to be the first people that come to mind. For instance, advances in smartphone technology are most likely attributed to large companies such as Apple or Samsung and the adult designers who work for them. When thinking about advances in space technology, you most likely think of them as coming from highly skilled adults with years of expertise. This is not surprising as research has shown expertise to be associated with inventions (Roux et al. 2018), and as expertise takes time to acquire it is therefore more appropriately associated with adults rather than children (see Roux et al., this volume, for an extended discussion on the role of expertise).

Although innovations in technology are not completely absent in children (see Rawlings and Legare 2020 for examples of innovations by children during the COVID-19 pandemic), the advances seen in modern technology that spread widely across the globe are rarely the product of innovations produced by children. So why have developmental psychologists, including myself, become interested in the development of innovation?

Children present researchers with the opportunity to examine the mechanisms involved in technological culture. Taking a comparative approach allows researchers to compare the abilities of humans with our nearest nonhuman primate relatives. By comparing performance on tasks requiring social learning and innovation, we can tease apart the differences and similarities between species, with the ultimate aim of discovering what is unique about humans that has allowed us and our technology to evolve beyond that of our nearest relatives. Children, rather than adults, are more appropriate to use for this research because of their relative lack of experience with the world. Of course, this does not imply that human children and chimpanzees have been raised with equivalent experiences, but children's relative naiveness to the world compared with adults gives us the best available opportunity to make comparisons. It is also assumed that the underlying cognitive and social mechanisms involved in innovation remain relatively unchanged over time, so our understanding of the development of these mechanisms in modern society can therefore inform our knowledge of these processes in our ancestors (Dean et al. 2012)

While children clearly contribute toward cumulative technological culture due to their vast capacity for learning new technologies and skills through social learning (see Hoehl et al. 2019), as stated previously, it is the second engine of cumulative culture that this chapter will focus on—innovation. Studying innovation in children gives us an opportunity to speculate when this capacity may begin in development and to explore the underlying cognitive abilities and mechanisms that are needed for innovation to occur.

The Role of Flexibility and Rigidity

Human propensity for cumulative culture demonstrates both technical rigidity and flexibility. The successful social transmission of useful tool behaviors requires rigidity. Human success in tool transmission has been credited to faithful (rigid) imitation of techniques (Dean et al. 2014; Tennie, Call, and Tomasello 2009; Tomasello, Kruger, and Ratner 1993). In contrast, the second component of cumulative culture—innovation—requires innovators to display flexibility. We must use our knowledge and skills in a more flexible manner to create new solutions, either by recombining our knowledge in new ways or by making new incremental improvements (Muthukrishna and Henrich 2016). Success in the technological domain that has allowed humans to occupy and thrive in varied environments worldwide clearly illustrates the species-level flexibility we have. What is less known is the flexibility we have as individuals in the technological domain (see Pope-Caldwell, this volume, for further discussion of this point). Behavioral flexibility can be demonstrated and measured at two levels (Ramsey, Bastian, and van Schaik 2007): flexibility in the behavioral repertoire (i.e., adding or removing behaviors) and flexibility in the behavior itself (i.e., modifying an existing behavior). Relating this to tool-innovation research, successful innovation of new tools represents repertoire flexibility. This is the first type of flexibility that I will explore. Then I will explore how the second level of flexibility differs depending on whether tool behaviors are the result of individual innovation or social learning.In the next section, I will give an overview of children's innovative abilities in the domain of tools by outlining research into independent, asocial tool-innovation that has been explored over the last decade, before going on to talk about more recent work investigating the social influences that affect children's ability to innovate.

Children's Toolmaking: Independent (Asocial) Tool-Innovation

As detailed above, children can learn new skills, including how to use tools, by watching and imitating those around them. This skill is evident from infancy (Nielsen 2006), and imitation becomes more faithful through development (Hoehl et al. 2019). In contrast to children's ability to faithfully replicate tool behaviors that they observe in others, children have great difficulty innovating tools for themselves. Initial investigations into children's ability to innovate novel tools measured innovative ability based on the notion that innovation is a predominantly asocial process that does not involve social learning (Ramsey, Bastian, and van Schaik 2007). It is also important to point out here that these studies do not expect individuals to come up with innovations that have never been generated by other individuals before—so-called historical (H) creativity (Boden 1996)—but instead measure innovative success as a new idea that is unique to the individual, or psychological (P) creativity. Under the asocial definition of innovation, behavior needs only to be new to the individual (Ramsey, Bastian, and van Schaik 2007).

The most common tool-innovation paradigm studied requires children to generate the idea of and manufacture a hooked tool from a pipe cleaner to fish a bucket out of a tall narrow tube (Beck et al. 2011) (see figure 11.1). This task was based on a study conducted with New Caledonian crows (Weir et al. 2001) in which a female crow "Betty" spontaneously manufactured a wire hook to solve the task when her mate "Abel" flew away with the tool needed to solve the problem. Children ages 3 to 10 were tested on the task, along with a "mature" sample of 16-year-olds. When asked to retrieve the bucket from the tube, children had remarkable difficulty producing the required hooked tool to complete the task. Very few children age 5 or younger were successful, with success gradually increasing with age, with just over half of children successful at age 8 and 80 percent successful at age 10 (see figure 11.2).

Children's difficulty with the "hooks task" has been shown to be robust across a number of studies conducted by multiple research groups (Cutting, Apperly, and Beck 2011; Gönül et al. 2018; Neldner, Mushin, and Nielsen 2017; Voigt, Pauen, and Bechtel-Kuehne 2019) and across cultures (Nielsen et al. 2014). Similar levels of success were observed in a sample of African Bushmen children whose culture necessitates manufacturing tools for themselves and consists of fewer premade tools than seen in Western society, where most tool-innovation research has been conducted.

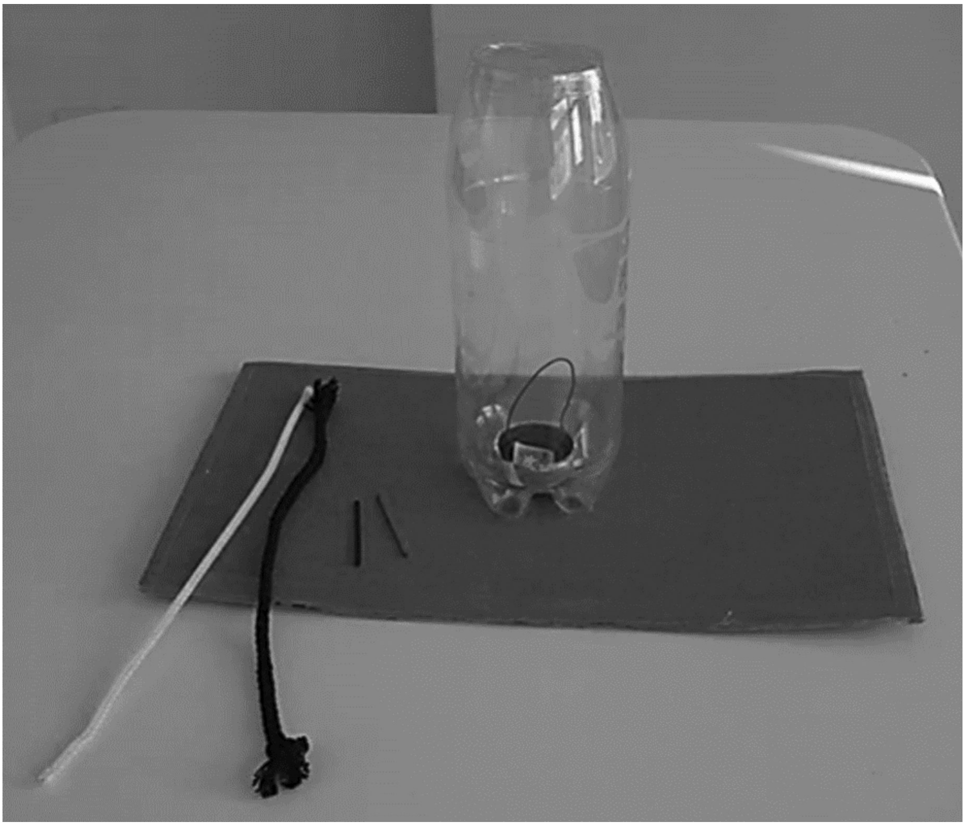

Figure 11.1
Apparatus and materials used in the "hooks task." *Source*: Photo by Author.

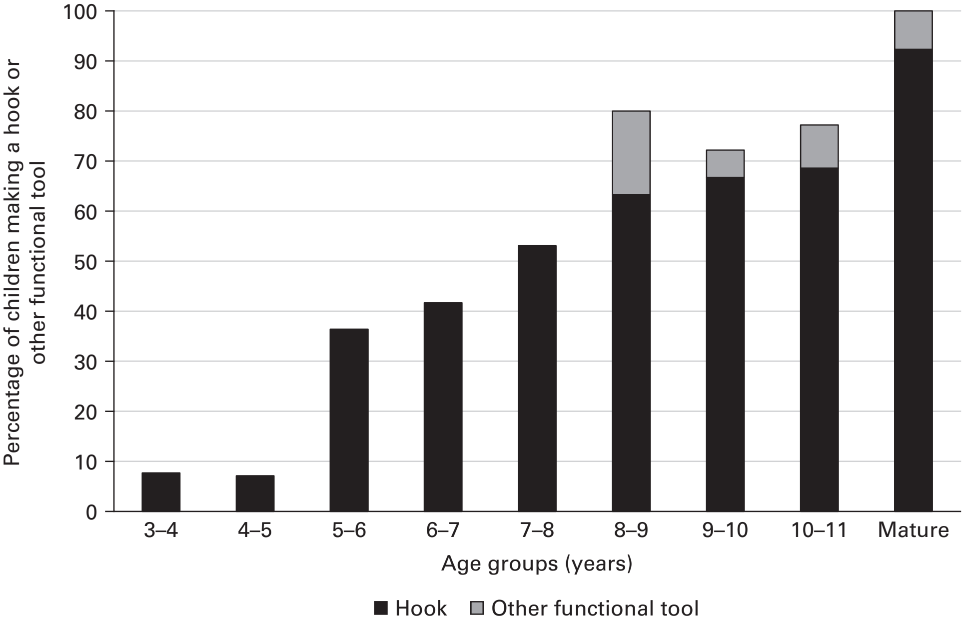

Figure 11.2
Percentage of children innovating a hook tool. *Source*: Recreated using data from Beck et al. 2011.

Most studies investigating children's tool-innovation ability have been based on the "hooks task" paradigm described above. However, a small number of other paradigms have been used and have generated similar findings. Similar levels of success were found on a task requiring children to innovate a long straight tool needed to push a reward from a horizontal tube (Cutting, Apperly, and Beck 2011). Children's difficulties innovating pipe-cleaner tools on tasks using a vertical tube (requiring a hook) and a horizontal tube (requiring a long straight tool) have also been shown to extend to studies requiring tools to be made from other materials (Cutting 2013; Neldner et al. 2019; Voigt, Pauen, and Bechtel-Kuehne 2019). The "floating peanut" task, requiring children to use water as a tool to retrieve a reward from a vertical tube by floating it to the top, is a different paradigm used to test tool-innovation ability. This task has generated similar success levels to the vertical- and horizontal-tube tasks (Hanus et al. 2011). Additionally, children aged 4 to 9 were found to have difficulty constructing variously shaped tools from LEGO sets to push a cube from one location to another inside a puzzle box (Mounoud 1996). Together, these studies suggest children's asocial innovation difficulty to be a robust phenomenon.

Why Is Independent Tool-Innovation So Difficult?

To date, research has focused on how children's tool-innovation ability may be constrained by cognitive capacity. It has been suggested that children's poor performance is due to the ill-structured nature of tool-innovation (Chappell et al. 2015; Cutting et al. 2014). Most problems we encounter in daily life are well-structured; they have clear start point and goal, and we simply choose between different options available to us. For example, in a tool-choice paradigm, we have a start-state of an apparatus containing a reward and two available tools;

the goal-state is to retrieve the reward, and the transformation to get from the start-state to the goal-state involves selecting the optimal tool to complete the task. In contrast, tool-innovation is ill-structured. The start-state and goal-state are the same as in the well-structured example, but there is little information of how to get from one to the other. The solver must generate and execute the solution for themselves (Jonassen, Beissner, and Yacci 1993; Reitman 1965). To do this involves executive ability. One must inhibit actions that are incorrect, switch between different strategies, and hold information about the problem in working memory. The difficulty of ill-structured problems is that they encompass all executive components in conjunction with each other and cannot simply be reduced to their component parts. The difficulty of ill-structured problems is demonstrated in studies with patients with frontal lobe damage (Shallice and Burgess 1991) and children with autism (White, Burgess, and Hill 2009). These participants were shown to perform at typical levels for lab-based executive tasks that tap individual executive functions but performed at comparatively lower levels in ill-structured tasks that required the use of multiple executive functions in conjunction with each other (Goel, Pullara, and Grafman 2001; Shallice and Burgess 1991; White, Burgess, and Hill 2009). It is therefore likely that the protracted development of children's executive abilities (Dumontheil, Burgess, and Blakemore 2008) may be a factor in their difficulty with ill-structured tool-innovation tasks.

Learning to Make Tools from Others: Imitation and Emulation

The above studies suggest that asocial innovation is very difficult for children. The design of these innovation studies also allows us to observe children's capacity to manufacture tools following social learning. In these studies, if children were not successful at innovating the required tool for themselves, then they next received a demonstration of how to manufacture the required tool, termed the "tool-creation demonstration." This provided children with the opportunity to imitate the correct toolmaking method. In some instances, unsuccessful children were provided with a demonstration in which the experimenter held their own pipe cleaner horizontally and manipulated one end to form the required hook tool (Beck et al. 2011; Cutting, Apperly, and Beck 2011). Importantly, in these demonstrations, the experimenter did not show the correct orientation the tool needed to be in or enter it into the apparatus. Despite not being a full demonstration of how to complete the task, the vast majority children (at least 80%) quickly modified their own pipe cleaner into the required hook tool and successfully retrieved the bucket from the tube.

These findings are in line with a wealth of research demonstrating that children easily learn how to manufacture their own tools by watching others. For example, from around 30 months, infants can manufacture a rattle toy consisting of three parts after watching a model (Barr and Wyss 2008; Hayne, Herbert, and Simcock 2003; Herbert and Hayne 2000).

Later tool-innovation studies included an additional demonstration phase for children. If children were unsuccessful at innovating a hook tool for themselves, they received what has been termed a "target-tool demonstration." In this demonstration, the experimenter showed children an example of the end-state tool, giving children an opportunity to emulate making the tool needed for the task rather than the opportunity to imitate the whole toolmaking process. As with the tool-creation demonstration described above, the end-state target-tool was presented in a horizontal orientation, and no demonstration of how to use the tool on the task was offered. Target-tool demonstrations were included in several tool-innovation studies (Beck et al. 2014; Chappell et al. 2013; Cutting et al. 2014, 2019), yielding modest improvements in children's ability to succeed on the task that did not reach the success levels seen after the tool-creation demonstrations. Children aged 6 to 7 were better able to emulate making a successful tool after seeing a target-tool example than younger children (Chappell et al. 2013), with most younger children requiring the full tool-creation demonstration to successfully complete the task.

Summary of Independent (Asocial) Innovation

So far, the presented research has shown that children find it extremely difficult to innovate simple novel tools for themselves, and this contrasts with their aptitude to learn how to manufacture tools from others. While tool-innovation undoubtedly involves cognitive skills, which likely makes it difficult, we must consider whether the tool-innovation paradigms discussed so far truly capture the nature of innovations that occur in real life. These paradigms require children to work independently with little social influence to create a novel solution they will not have encountered before. These environments stand in contrast to the highly social worlds that children inhabit.

There are two key factors of innovation studies that need to be addressed. First, real-world innovations are likely to involve more social influence. Rather than being isolated, innovators are more likely to be surrounded by other individuals and other forms of social information. Second is the type of innovation that these tasks require. Although children will likely have some experience with the properties of pipe cleaners because they are a common craft material in schools and nurseries, and children are likely to have knowledge about hooks, the requirement to create this novel tool is very much a step-change. While such step-change innovations do occur, they are likely to be a rare form of innovation and would be characterized as an innovation by recombination. The next section explores research that has looked at the scaffolding of innovations and how children use social information to help them construct novel tools without the need for full demonstrations of tool manufacture.

Socially Mediated Tool-Innovation: Can Information from Others Help Children to Innovate Tools?

Many studies have aimed to investigate the mechanisms underlying tool-innovation to try to establish where children encounter difficulty. Although not the stated purpose of these studies, their design of providing information to children within a social context allows us to draw some conclusions about socially mediated innovations more akin to those likely to occur in real life. This section outlines these studies and discusses the contribution they make to our understanding of children's ability for socially mediated innovations.

Affordances

Although children are presumed to have knowledge of the pliable properties of pipe cleaners, this was confirmed by a study in which one group of children took part in a warm-up exercise manipulating pipe cleaners by winding them around a pen and creating spiral shapes (Beck et al. 2011). Highlighting the affordance of the pipe cleaners in this social manner did not improve innovation and was therefore taken as evidence that children already possessed knowledge of pipe-cleaner properties.

As stated previously, one of the main difficulties of the current recombination-style tool-innovation paradigms is the high cognitive load placed on children. They must first generate the idea of a hook tool and then recognize the utility of the pipe cleaner in allowing them to achieve this. The tool-choice paradigm presented by Sarah Beck and colleagues (2011) demonstrated that children could easily recognize the utility of a hooked tool, quickly and effectively using it to solve the task; however, this task did not have an innovative component. Karri Neldner, Ilana Mushin, and Mark Nielsen (2017) sought to reduce cognitive load while maintaining the need for innovation. In this study, children were presented with a hook tool that had the non-hooked end curled over, preventing it from entering the apparatus. The provision of the focal affordance (hook shape) as visual information reduced cognitive load as children were only required to recognize rather than generate the appropriate affordance of the material. I would argue that the design of this task would put it in an innovation category closer to incremental improvement. Children aged 3 to 5 were nine times more likely to innovate a functional tool when the focal affordance was visible. However, successful innovation was still only seen in 45 percent of children (compared to 14% in the affordance nonvisible condition), showing that although children were helped by the reduction in cognitive load and social information, innovation was still a difficult feat for young children.

Nonfunctional Tool Examples

Another study that used social information in an attempt to scaffold children's tool-innovation presented children with a correctly shaped but nonfunctional tool (Cutting et al. 2019). The researchers presented children with oversized pipe-cleaner hooks with which to solve the vertical-tube problem. However, rather than scaffolding innovation and acting as a prompt for creating the required tool, the presence of the oversized hook appeared to hinder children's ability. In line with other studies (Beck et al. 2011; Neldner et al. 2019), children easily recognized the affordance of the hook tool, choosing to use the oversized hooked pipe cleaner significantly more than the straight pipe cleaner. However, children were poor at modifying the nonfunctional hook into a functional tool or manufacturing their own correctly sized hook from the straight pipe cleaner provided. In fact, compared to a baseline condition where children received two straight pipe cleaners, children who received an oversized hook and a straight pipe cleaner were less likely to create a functional tool to solve the task. This therefore suggests that the presence of a correct but nonfunctional tool actually hindered children's ability to solve the problem at hand.

In comparison to the original innovation by recombination hooks task, this paradigm (like Neldner et al. 2019) required a modification or innovation by incremental improvement. Children were presented with the right sort of tool, but it was nonfunctional. Considering the types of innovation discussed, it could be expected that this task should be easier for children to complete, as we would expect innovation by incremental improvement to be more common and easier to achieve than innovation by recombination. A number of explanations for children's difficulty and lower success rates were proposed in the paper (Cutting et al. 2019).

Building on the cognitive load theory of Neldner and colleagues (2019), one possibility proposed was that instead of acting as a clue to help children, the presence of the nonfunctional hook actually increased cognitive load. In contrast to the Neldner study where children simply needed to recognize the affordance of the hooked end of the material, in this study children needed to not only recognize the affordance of the hook but also realize that it was too big for the task and execute a plan of successful modification. These added requirements may have been more cognitively demanding than simply needing to recognize the solution and executing it for oneself.

Another proposed explanation was that the children's behavior was due to them being preprogrammed to learn from others, especially adults. Adults teach children and provide them with useful information; it therefore seems likely that children expect to receive useful information and help. They may interpret the testing paradigm as a situation in which the adult present is likely to provide useful and relevant information and products. They may expect that the materials they are given are ones that will be needed and will work to solve the task they are presented with. This disposition for social learning may hinder children in the context of innovation because they are not expecting to innovate; they are expecting to be taught how to solve the problem rather than figuring it out for themselves.

Building on these suggestions, I will now propose a third factor that is likely to have contributed to children's poor performance on this task—lack of expertise. Socially transmitting relevant information about aspects of the task to children is unlikely to be sufficient to help them innovate a novel tool. Valentine Roux and colleagues (this volume) show that the ability of skilled potters to create new shapes demonstrates that only the most skilled potters with the highest expertise had the flexibility to achieve these new designs. Similarly, the ill-structured problem-solving literature suggests that well-integrated structural knowledge of a concept is needed to solve ill-structured problems (Jonassen, Beissner, and Yacci 1993). It may therefore be unsurprising that providing children with small pieces of information relevant to the task might not be sufficient to induce innovations. I expand on this further in the section below, where I present a study that provided children with multiple pieces of relevant task-related information.

Multiple Scaffolds

The study (Cutting et al. 2014) explored children's ability to use information from others to innovate a hook tool. Half of children participated in an exercise that socially demonstrated pipe-cleaner bending before the innovation task; the exercise was meant to highlight the affordances of the materials. If unsuccessful on the tool-innovation task, children then received a target-tool demonstration. The design of this study allowed researchers to assess children's ability to use this social information regarding different aspects of the task. It was concluded that children's main difficulty was with generating necessary information for themselves (i.e., that a hook is needed, that pipe cleaners are pliable, etc.). When given this information, children age 5 and older were able to use it to create a successful solution to the task. However, children younger than age 5 lacked this flexibility and had great difficulty combining the different pieces of information even when presented by the researcher.

Let's revisit and attempt to apply the three explanations given for children's poor performance on innovation tasks. First is the cognitive load theory of Neldner and colleagues (2019). The current paradigm provides children with a reduction in cognitive load by presenting the various elements of the task that then need to be combined—pipecleaners bend, plus hook-shape. When provided with both elements, children over age 5 increased their chances of success, providing clear support for this theory. It is likely that younger children are lacking in the required baseline cognitive capacity to combine the information. This is supported by evidence that children's executive functions show protracted development across childhood with greater gains once children begin formal education (Hughes et al. 2010), which is around age 4 to 5 in the United Kingdom, where this study took place.

Second, the expectation that adults provide knowledge may have aided children with this task. In contrast to being given an oversized hook by an adult (Cutting et al. 2019) that may have inadvertently been interpreted as the solution, this task communicates numerous pieces of information to children, which are potentially correctly interpreted as being useful for the task.

Third, although some improvement in performance was seen with increasing social information, children did not reach high performance on the task. This could again point to the need for expertise before children can flexibly use information. It is possible that older children who were more successful have more experience with the materials, but this is difficult to disentangle from their advanced cognitive capacity. Future studies should introduce novel materials to help disentangle the roles of these factors.

Transfer of Toolmaking Knowledge

Asocial and socially mediated innovation has been shown to be difficult for young children, demonstrating that in the technical domain, children lack flexibility in their behavioral repertoires (Ramsey, Bastian, and van Schaik 2007). The next question that arises is whether children display behavioral flexibility at the second level—that is, for the tool behavior itself. For techniques to prosper, it is important that they are retained for future use (von Hippel and Suddendorf 2018). The tool-rich world we live in today could not exist if we did not retain information we learn about how to make and use tools. At the first level, it is important that once a new technique (e.g., making and using a hook tool) has been learned, this technique can then be replicated for the same task on future occasions. Second, there also needs to be some degree of flexibility in how the technique is used because it is unlikely that all tasks will require the exact same solution (i.e., there will be slight variations in the tools required).

Replicating a Learned Technique

Children demonstrate an excellent ability to manufacture identical tools on the exact same task following their own initial innovation. In a study that I participated in (Whalley, Cutting, and Beck 2017), children were presented with three trials of the hooks task, and their success on the task was stable across trials. Children who innovated a hook tool replicated their successful solution on subsequent trials. While this ability to retain useful innovative information is reassuring, this task is limited in that the trials were presented in quick succession, and we are only able to assess whether spontaneous innovations are retained for future use.

Beck and colleagues (2014) provide more substantial evidence for children's ability to retain toolmaking knowledge. Children were tested on the hooks task twice with a three-month gap in between. In the first presentation of the task (time 1), children were recorded as successfully innovating a hook tool or successfully manufacturing a hook tool following either the target-tool or tool-creation demonstration. Successful innovation was then measured at time 2. Children retained knowledge of toolmaking over the three-month period, with the ability to manufacture the tool pre-demonstration in each session rising from 0 to 71 percent in four- to five-year-olds and 16 to 68 percent in six- to seven-year-olds. There was no difference in success at time 2 depending on whether children spontaneously innovated at time 1 or received either of the demonstrations. However, low initial success rates and small sample size may be masking differences in how these factors affect retention rates.

Making Flexible Use of Learned Techniques

While exact replication of a technique is important for the retention of that technique, to drive cumulative cultural evolution, techniques need to be transferred to new tasks. The distance between the original task and the new situation will determine how much the technique evolves. Near or close transfer refers to the ability to apply learning in very similar contexts involving little flexibility in a technique, whereas far transfer refers to the ability to adapt learning to more dissimilar contexts showing greater flexibility in techniques (Sala et al. 2019). In close transfer tasks, children demonstrate some ability to flexibly transfer knowledge of making hook tools to tasks that vary only in surface characteristics. Beck and colleagues (2014) presented children with three versions of the hooks task one after the other: the original clear tube and bucket, a shorter green tube containing a blue bucket with closed-loop handle, and a cuboid clear transparent box with a square yellow bucket. Each task was presented with its own different-colored pipe cleaners and string distractors. On each version of the task, children were given an opportunity to innovate a tool for themselves and then received a tool-creation demonstration if necessary. Performance on the first task was low for all children, with five- to six-year-olds demonstrating a better ability to flexibly transfer knowledge to the new tasks (rise in success rate from 5 to 86%) than younger three- to five-year-olds (rise in success rate from 4 to 50%).

Children's ability for far transfer was tested on a task requiring them to retrieve rewards from the same apparatus using different materials. Children were unable to transfer their knowledge of hook-making with one type of material (pipe cleaners) to a second task using the same apparatus requiring them to create a hook tool using different materials (wooden dowels added together) and vice versa (Beck et al. 2014). Despite either independently solving the task by making a hooked tool or being shown how to make a tool, children were unable to use their knowledge of the tool required to make a successful tool from a new material.

Children's lack of flexibility for far transfer is confirmed by studies requiring children to make two different tools on two different tasks. Knowledge of the affordances of the pipe-cleaner materials available did not help children to make their second tool after success was achieved (either independently or with social learning) on the first task (Cutting, Apperly, and Beck 2011).

Together, these studies show that once children have learned a new tool technique, either independently or through social learning, then this knowledge is robust over time and can be readily deployed on tasks with the exact same parameters. Children also display some level of flexibility in their behavior. By age 6, children can use this knowledge on tasks with the same underlying task requirements but differing surface characteristics (close transfer or small modification). As the task requirements diverge further away from the original, children display a lack of flexibility and struggle to transfer their knowledge about the required tool shape to new materials (far transfer or large modification). This could be taken as evidence that innovation is a domain-specific rather than domain-general skill (Rawlings and Legare 2020). Additionally, this could be taken as further support for the role of expertise. As discussed previously, expertise and the ability to innovate have been closely linked (Roux, Bril, and Karasik 2018; see also Roux et al., this volume). It is therefore likely that for children to flexibly use the knowledge that they have gained, they must reach some level of expertise. Given that hook-innovation tasks have only given children a small amount of experience in making a hook tool (in most cases only one attempt), it is therefore unsurprising that children do not have enough experience to be able to flexibly use their new knowledge and modify it to new situations.

Bringing It All Together

Children demonstrate a lack of flexibility in the domain of tools. Despite having remarkable aptitude to learn how to make and use tools by imitating or being taught by others, children's ability to innovate simple tools has consistently been shown to be difficult. Initial studies into children's tool-innovation focused on independent, asocial innovation. These tasks yielded very low levels of success and were an important starting point in our understanding of children's ability to innovate. However, it seems likely these studies do not give us true insight into how innovative abilities develop. Innovations are likely to be much more socially mediated, and it is important that paradigms capture this. Some of the more recent studies described in this chapter give us an indication as to how children use social information to make innovations by modification, and they suggest a complex picture.

Social Influences in Tool-Innovation

There are two factors that we need to consider about the tool-innovation studies that have been presented in this chapter—type of innovation required and amount of social influence. These factors overlap and intertwine. I would argue that all of these studies, whether categorized as asocial or socially mediated innovation, contain some degree of social influence because of the nature of the world we live. At one end, we have social models who can demonstrate behaviors and techniques that we are able to imitate; at the other end, where there is an absence of direct modeling or instruction, information is still available to us through the context of the scenario we find ourselves in and because the materials provided for us have been manufactured and therefore must have some designed purpose (Dennett 1987). Tasks requiring individual innovation by recombination have been termed here as "asocial" and would be placed toward the asocial end of an asocial–social spectrum. However, these tasks still involve some degree of social influence. The tasks are presented to children by an experimenter who clearly has a motive for presenting the child with the apparatus and materials. The materials themselves have clearly been manufactured for some purpose (see Boyette, this volume, for a discussion on how tools give us insight into those that make them).

Studies that have investigated innovation by incremental improvement or modification contain a greater degree of social influence as innovations build on the social outputs of others. The modification studies in this chapter vary in the amount and type of social information transmitted to participants. There is some evidence to suggest that greater social input has a positive effect (Cutting et al. 2014; Neldner, Mushin, and Nielsen 2017), but these independent studies do not yet create a systematic narrative to help draw firm conclusions about the role of social influence on children's innovations or the degree of modification required and the impact they have on children's innovative ability.

Linking with the earlier discussion surrounding the requirement of expertise for innovations to occur, a logical starting point to investigate children's capacity for incremental innovations would be to train and give children expertise in making a tool of a particular configuration before then introducing new apparatus requiring the modification of the size or shape of the tool (see Pope-Caldwell, this volume, for a framework to test this notion). Once a baseline of the expertise required for flexibility for modification has been established, studies can then investigate along the social–asocial continuum in a more systematic way.

Revisiting and Expanding on the Idea of Expertise

Valentine Roux and colleagues (this volume) provide an excellent discussion and evidence for the role of expertise in the flexibility of techniques. Expertise is a factor that has been thus far overlooked in the developmental tool-innovation literature, but it is a factor that needs to be explored. In the previous section on flexible use of learned techniques, I speculate on the role expertise may play in children's ability to adapt and modify their learned tool behaviors. The topic of expertise fits with my discussion of tool-innovation as an ill-structured problem-solving task (see Cutting, Apperly, and Beck 2011; Chappell et al. 2015). In various hook-innovation studies, children have been poor at piecing together the individual components of the task to create the solution (see Cutting et al. 2014). The ill-structured problem-solving literature suggests that only experts have well-integrated knowledge that can be used flexibly to solve problems (Jonassen, Beissner, and Yacci 1993). Therefore, providing children with the pieces of information is not enough to allow them to use this information flexibly to solve the problem. The question that arises, then, and that I previously posed, is just how much of an expert do you need to be to innovate? Studies with children offer us one way to approach this question, because children's limited experience with the world means we can more easily manipulate their expertise with techniques, which will hopefully allow us to address this question.

Why Innovate If You Can Imitate?

This idea of expertise, which is very much domain-specific, is linked to a domain-general factor that has not been particularly addressed by the literature. It is the fact that children (and adults) do not have much, if any, need in their lives to innovate new tools. Society has reached a point in our cumulative technological evolution that we are surrounded by an abundance of tools for almost any purpose we can think of. Of course, there will always be advances in technology, mostly innovations by modification that will be conducted by experts who will design the new generations of smartphones and televisions with better-quality screens and more efficient batteries. There will also be some step-change innovations by invention that will change the ways that we conduct our lives in ways that we cannot possibly imagine today. But for a five-year-old child living in Western society, I would argue that they are currently surrounded by all the tools they need, and so innovation is just not something that needs to be exploited. The tools they need to use throughout their daily lives are readily available to them (financial means permitting), and rather than working out how these function for themselves, children are surrounded by people they can model their use on—parents, siblings, peers, and teachers.

If a young child wants to use or create new technology but does not know how, the most efficient way to learn is to watch other people engaging in the same activity or asking someone to model the method. Our culture is so socially connected that even if we do not have someone in our immediate network who can demonstrate something for us, then we can find a solution to our problem simply by typing prompts in ChatGPT or watching a video on YouTube. There are very few scenarios where someone is unsure of how to do something that cannot be solved by asking someone in your network or reaching out to the depths of the internet, and these are much quicker and efficient ways to reach a solution than by trying to innovate one independently (see Pope-Caldwell, this volume, for an extended discussion on how we only behave flexibly at an individual level when we are forced to).

My main argument is that most people in the modern Western world, children but also adults, just do not need to innovate especially in the domain of tools throughout their everyday lives. Building on this, I would argue that historically, for cumulative technological culture to exist, not everyone needed to be an innovator. It only takes one good idea, or one successful variation in what has gone before, for an innovation to occur. The important part, as evidenced in the literature, is for that innovation to then spread throughout the group by social transmission so that all group members adopt the new more efficient outcome (Dean et al. 2014; Tennie, Call, and Tomasello 2009; Tomasello, Kruger, and Ratner 1993). If everyone was an innovator, then the whole system would become somewhat messy. If everyone were constantly trying to improve on a tool, it would make it difficult to see which innovations were the successful ones. There would be too much data to process and no clear indication of which tool or method was the right one to use. Focusing on innovation may also take the focus away from social transmission, and without the new and more efficient ideas spreading throughout the group, cumulative evolution could not occur (see Tenpas, Schweinfurth, and Call, this volume, for a discussion surrounding how overly flexible groups can lead to cultural breakdown). We therefore need to balance a high number of social learners and a much smaller number of innovators. What needs to be determined is whether the most successful groups leading to high levels of cumulative cultural evolution consist of individuals who are either innovators or social learners and what frequencies of each are needed, or whether individuals can be both innovators and social learners at different times and what the optimum frequency of innovations is. If the first option is true, then we need to identify what makes someone an innovator, and studying children is one way to answer this question.

Conclusions

Research with children has the potential to inform us about the required mechanisms and flexibility that underpin the ability to innovate new tools. As a relatively new field, research to date has predominantly used the hooks task to measure capacity for innovation by recombination. While this begins to answer some questions about the cognitive mechanisms involved in tool-innovation, the relative asocial nature of this paradigm does not replicate innovations more commonly seen in real life, which I argue are more socially influenced. More recent work has begun to investigate incremental innovations or modifications more akin to those that fuel cumulative evolution. These studies suggest some flexibility in the way that children use their tool knowledge, but these studies need to be conducted and integrated in a more systematic way that can tease apart the roles of social influence, expertise, cognitive demands, and whether the skills required for innovation are domain-specific or domain-general.

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