Innovating for the future: When do children begin to recognise and manufacture solutions to future problems?

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Abstract

Innovation in children is typically studied by examining their capacity to create novel tools. However, innovation also involves recognising the future utility of a solution. Across two experiments, we examined children's capacity to recognise and construct a tool for future uses. Experiment One presented 3- to 5-year-olds (N=55) with a future-directed problem-solving task. When given a tool construction opportunity in anticipation of returning to the task, only 5-year-olds made the correctly shaped tool above chance levels. Experiment Two assessed 3- to 7-year-olds' (N=92) capacity to build a tool with future, as well as present, utility in mind. Age was positively associated with constructing a tool of greater utility than necessary to solve the present task. Children's propensity to construct longer tools was associated with their capacity to prepare for two alternative possibilities on a secondary task, suggesting performance on our innovation task reflects emerging future-oriented cognition.

Keywords: future utility; innovation; foresight; tool use; problem-solving; cognitive development; children.

Introduction

Tool innovations play a crucial role in human society. They enable us to overcome our physical and cognitive limitations, making otherwise impossible feats – such as conversing with someone halfway across the world – commonplace, everyday events. And while some technologies may become part of a culture's repertoire by means of blind cultural evolution processes (Derex et al., 2019; Henrich, 2021; Legare & Nielsen, 2015), humans also deliberately build and conserve solutions to prepare for specific future problems.

Take Alexander Fleming's discovery of penicillin. It was only by chance that he observed *Penicillium* mould killing bacteria in a Petrie dish. But rather than cleaning the dish, and discarding the mould with it, he recognised that the mould might be utilized as a treatment for bacterial infections. Fleming was, of course, correct, and his sharing of this knowledge with scientific and medical communities helped transform it into a ground-breaking medical innovation.

This capacity to identify a solution to a problem and then recognise that it has utility in the future has been identified as a critical feature of human innovation (Suddendorf et al., 2018). Recognising future utility motivates us to keep a solution to use it again and again, to refine or hone specific features to improve its effectiveness or durability, and of course share it with others in our group – whether for benevolent or financial reasons.

Research examining children's capacity for tool innovation, however, has so far predominantly focused on their ability to create a novel tool to solve a one-off problem (Cutting, 2011). The most prolific paradigm, the hook task (Beck et al., 2011; Weir et al., 2002), requires children to retrieve a bucket from a transparent vertical tube using a pipecleaner. While 4-year-olds can easily solve this task if given both a straight pipecleaner and a pre-hooked pipecleaner to use, they do quite poorly when only provided with a straight pipecleaner; it is not until around eight years of age that around 80% of children will hook one end to manufacture the solution themselves (Beck et al., 2011).

More recent variations to the hook task paradigm have shown that slightly younger children can solve this problem when they are provided with sufficient time and resources (Burdett & Ronfard, 2023; Voight et al., 2017), when tool affordances are made clearer (Neldner et al., 2017), and when the tube apparatus is oriented horizontally rather than vertically (Breyel & Pauen, 2021). However, all these studies focus on children's capacity to create a solution to a present problem, and do not capture their capacity to recognise the future utility of the tool. Such paradigms can therefore offer no insight into the developmental origins of this future-directed aspect of innovation.

Episodic foresight describes our capacity to imagine future situations and organise current behaviour accordingly (Suddendorf & Moore, 2011). Through this capacity we can consider the potential outcomes of our actions and use those imagined futures to inform our current decision-making. Recurring situations can be predicted simply by casting forward, as it were, a memory of a past event. But people can also imagine situations they have never experienced before. When mentally constructing these types of events we can combine elements from memory and current experience into novel variations – just as we can combine words into infinite new sentences (Suddendorf and Corballis, 2007).

Foresight develops gradually over childhood (for review, see Hudson et al., 2011; McCormack & Atance, 2011; Suddendorf, 2017; Suddendorf & Redshaw, 2013). Many 4-year-olds (Redshaw & Suddendorf, 2016) and perhaps even

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3-year-olds (Turan-Küçük & Kibbe, 2024) can conceive of and prepare for two alternative events in the immediate future. By 4 years of age, children can also identify and obtain a tool in the present, in preparation of solving a problem they had encountered in the recent past (Suddendorf et al., 2011). This finding demonstrates some capacity for future-oriented combinatorial thought in 4-year-olds, such that they could mentally combine their memory of the unsolved problem with their perception of the tool in the present to recognise it as a future solution. It remains unknown, however, when children can construct their own solutions to future problems.

Across two experiments, we examine for the first time when children can recognise and then construct a useful tool to solve a future problem, thus demonstrating some capacity for this basic component of innovation. Our first experiment adapts the hook task paradigm to include a future-directed component. Our second experiment introduces a novel construction task to examine when children can make a tool that will solve a present *and* future problem rather than just a present problem. We sampled children aged from 3 years onwards, given that this is just before children begin to show strong evidence for basic foresight capacities.

Experiment One

Method

Participants

The final sample included 55 children aged between three and five (*M* = 55.04 months, *SD* = 9.90 months, 28 female) recruited from the general public at the Queensland Museum in Brisbane, Australia. Nine other children were tested but excluded from analyses due to seeing another child complete the task (n=8) and lack of attention (n=1). An *a priori* power analysis indicated that a sample size of 45 children would yield an 80% chance of detecting medium effects (equal to *r* = .40), although a larger sample was ultimately collected given the public location of our data collection. This study's design and analysis plan was preregistered; see here.

Materials

Two plastic mats were used to represent location one (henceforth 'red mat') and location two (henceforth 'yellow mat'). The hook task apparatus was functionally identical to that used in Beck and colleagues' (2011) study, with small variations. It consisted of a blue-tinted transparent PVC tube mounted vertically on a wooden L-shaped base (see Figure 1), and inside the tube was a small blue bucket containing a marble. An unbent pipecleaner and five pictures representing possible shapes the pipecleaner could be molded into were provided to the children (the size of the shapes themselves were proportional to the pipecleaner length; see Figure 1).

Procedure

Children were directed to sit at the red mat and introduced to the hook task. It was explained that they needed to retrieve the marble from the tube using items on the red mat (the only item present was the hook task apparatus itself), and if they did so they would receive a sticker reward. After children were given sufficient time to examine the task, the experimenter stated that it was not currently possible to get the marble out and that they could try the yellow mat game instead. The hook task was then covered with an opaque cloth, and children were told that after they finished the upcoming yellow mat game, they would return to the red mat and be given another chance to retrieve the marble.

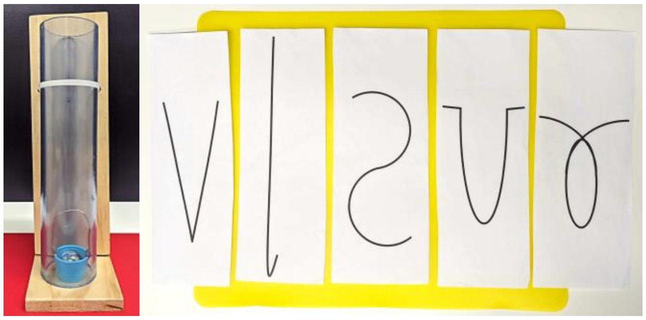

Figure 1. Hook task apparatus (left) and the five tool shape options presented to children (right). Here the correct hook shape appears second from left (order randomised).

On the yellow mat, children completed a distractor task which took approximately 5-minutes before being told that there would be a final activity to complete before returning to the red mat. A pipecleaner and five pictures of shapes (placed in a placed in a randomised order differing across children) were revealed, and children were instructed to choose one of the five shapes to make with their pipecleaner to take back to the red mat. Once children molded their pipecleaner into the selected shape (either independently or with assistance from the experimenter), they returned to the red mat and completed the hook task.

Results and Discussion

Only 26% of children (14/55) selected the correct shape, and made their pipecleaner into a hook, which was not significantly different from chance (20%), *p*=.197. There was no association between age and selection of this shape, $r_{pb}(53)=.22$, *p*=.103. However, binomial tests revealed that while 3-year-olds (3/15; 20%) and 4-year-olds (3/21; 14%) did not perform above chance (20%), 5-year-olds did perform significantly above chance (8/19; 42%), *p*=.023. So, although 4-year-olds can recognise and obtain a pre-made solution to the hook task above chance when the problem is oriented in the present (Beck et al., 2011), our findings suggests that it might take longer before children can identify and build the correctly shaped tool from an available selection when the task is oriented in the future. This interpretation is in line with previous findings showing that 5-year-olds, but not 4-year-olds can plan for a future problem when associative explanations are controlled for (Dickerson et al., 2018).

The 5-year-olds' success on this task also contrasts with their apparent poor performance on traditional versions of the hook task (Beck et al., 2011; see Breyel & Pauen, 2021 for review). This pattern suggests that while children of this age may struggle to create a novel tool to solve a problem, many of them are capable of recognising a potential solution when they see it, and can extrapolate that knowledge to build a useful tool in preparation for a future problem. Further, there is evidence to suggest that children underperform on the hook task in comparison to other simpler problem-solving tasks such as the horizontal tube task (Breyel & Pauen, 2021), meaning children's capacity to recognise future utility may have even been underestimated in our Experiment One. Thus, in Experiment Two we addressed this possibility by examining children's capacity to build a tool for a task that involved simply pushing a ball out of a tube.

Experiment Two

While Experiment One focused on whether children can recognise and build a tool in the present to solve a future problem, Experiment Two directly contrasted children's capacity to (i) construct a tool with only present utility in mind, with their capacity to also (ii) consider the future needs of their tool. To this end, children were exposed to both a present- and future-oriented task that both required a straight poking tool to solve, and were then given an opportunity to connect a number of dowel pieces in the context of the present-oriented task. Critically, the present-oriented task could be solved with a shorter poking tool than the future-oriented task, and thus children had to construct a tool longer than necessary to solve the present-oriented task if they wanted to solve both tasks.

As constructing such a tool may be related to one's capacity to prepare for multiple possibilities, children also completed a version of Redshaw and Suddendorf's (2016) forked tube task, to assess whether performance across the tasks was related. Finally, given that Experiment One did not find a linear age effect, possibly due to the narrow age range, Experiment Two expanded the age range up to 7 years.

Methods

Participants

The final sample included 93 children between 3 and 7 years (*M* = 64.58 months, *SD* = 16.34 months, *range* = 36-95 months, 48 female) recruited from the general public at the same museum as for the previous experiment. An additional seven participants were tested but excluded from analyses due to lack of attention (n=3), experimenter error (n=3), and seeing another participant complete the tasks (n=1). An *a priori* power analysis indicated that a sample size of seventy-five children would yield a 95% chance of detecting a medium-large association equal to r = .40), between age and overall tool length, however a larger sample was ultimately collected given the public location of our data collection. This study's design and analysis plan was preregistered; see here.

Materials

Tool construction task. A red and a yellow plastic mat were again used to represent locations of the present- and future-oriented tasks, respectively. Three identical but differently sized diagonal tube apparatuses (1x40cm tube, 2x20cm tubes) were set up across the two mats. The 40cm apparatus was positioned on the red mat and the two 20cm apparatuses on the yellow mat, although only one 20cm apparatus was in view at any one time (see Figure 2). Each apparatus consisted of clear PVC tubing connected to a right-angled triangular wooden base. Located inside each of the tubes was one fabric 'pom-pom' ball. The apparatuses sat atop a transparent container which also acted as a cover for the yellow mat apparatuses while an opaque, black container was used as a cover for the red mat task. Seven connectable dowel pieces (see Figure 2) could be combined to build a tool to dislodge the ball from the tubes if enough piece were connected.

Figure 2. *Top:* tool construction task. *Bottom left:* dowel pieces for tool task. *Bottom right:* forked tube apparatus.

Forked tube task. Children also completed a smaller, but functionally identical, version of the forked tube task (Redshaw & Suddendorf, 2016; see Figure 2) as a secondary measure. The forked tube consisted of three blue-tinted transparent PVC tubing sections connected by an opaque plastic junction box. The experimenter could control the path a ball would take (either down the left or right bottom exit) once dropped into the opening at the top of the apparatus. Small marbles were dropped into the tube and, if caught, children placed them in a small plastic container. If uncaught, the marbles would roll down a ramp and land in a plastic container which children were told they could not access.

Procedure

Tool construction task. Children were first introduced to a hand puppet, 'Caw the Cockatoo', who was placed between the two tasks and served to justify the existence of the tasks' rules (see Figure 2). They were told that they would receive three stickers if they could complete the red mat game but no stickers if they could complete the yellow mat game (in order to heighten the importance of the future-oriented task on the red mat). Both the red and yellow mat tasks were visible to children at this point to ensure they were aware that the red mat task was in fact longer than the yellow mat task.

Children were directed to sit at the red mat. It was explained that they needed to retrieve the ball stuck inside the (40cm) tube by inserting something into one end of the tube that would push the ball out the other end using only the items on the red mat to help them. These instructions were given to eliminate the creative problem-solving aspect from the task and to ensure that failure on the task was not merely a result of insufficient understanding of task mechanics. After children either attempted to solve the task or examined the task and mat contents further, the experimenter commented that the task was not currently solvable. Children were then asked to move to the yellow mat but were told that they would return to the red mat later to have another opportunity to solve the task. The red mat apparatus was then covered to ensure that children could not see the future-oriented task.

First tool construction phase. On the yellow mat, children were again told that they needed to retrieve the ball stuck inside the (smaller, 20cm) tube. The task instructions given here were identical to those given on the red mat except the container holding the connectable dowel pieces (located on the yellow mat) was also introduced. To again ensure the creative aspect of the task was removed for children, it was explained that they could connect the pieces together to make a tool long enough to solve the current task. Crucially, however, no explicit reference to the longer task was made and children were only told that the tool they made on the yellow mat could be taken back to the red mat.

To encourage children to consider their tool's utility, they were required to make it prior to solving the yellow mat task and any unused pieces were put away after the construction period. A transparent cover was placed over the apparatus before the tool making phase commenced to give children the opportunity to compare the length of their tool to the present-oriented problem. When children finished constructing their tool the apparatus was uncovered, and children were invited to complete the task. If children had used all of the available dowel pieces, they returned to the red mat so they could also solve the future-oriented problem. If children did not use all seven pieces, they remained on the yellow mat and received a second opportunity to construct a longer tool.

Second tool construction phase. Given the high cognitive demands of the task (i.e., following multiple, complex verbal instructions; understanding task mechanics via merely imagining a potential tool could push the ball out of the shorter tube), a second construction opportunity was included to attenuate the risk of false negatives. Here, children no longer needed to rely on imagining the mechanics of how a ball can be removed from a tube—but, critically, were still required to extrapolate from experience and estimate the length of tool needed to solve the longer, future task.

A second, unsolved 20cm tube apparatus was presented to this subsample of children. Task instructions were identical to those given in the first tool construction phase, and children had the option to add any remaining dowel pieces to the tool they had made during the first tool construction phase. After constructing their tool and retrieving the ball from the tube, the children then returned to the red mat so they could attempt to solve the future-oriented problem.

Forked-tube task. After completing the tool construction task, children were told they would play a catching game. Following Redshaw and Suddendorf's (2016) original study, children watched a demonstration of six balls being dropped through the forked tube in succession in a pseudorandom order (*right, left, left, right, left, right*). They were then told it was their turn to catch and that they could do "whatever they liked" to catch as many as possible. Children received twelve trials (same order as demonstration, repeated twice) and were scored for whether they covered both exits on each trial.

Results

First tool construction phase

Tool length. All ninety-two children (100%) connected at least two dowel pieces together (*M* = 5.42 pieces, *SD* = 1.64 pieces), which was the minimum length needed to solve the present-oriented task. Thirty-nine children (42%) used all seven pieces and hence constructed a tool capable of solving both the present- and future-oriented tasks (see Table 1). Twenty-two other children (24%) made a tool longer than the tube used in the present-oriented task (i.e., five or more pieces; see Figure 3). Therefore, in total, 61 children (66%) constructed a tool of greater length than the tube in the present-oriented task (see Table 1).

Table 1: Tool length after the first construction phase and pooled across first and second (if necessary) phases.

Age group	First construction phase: Sufficient for both tasks	First construction phase: Longer than present tube	First and second phases, pooled data: Sufficient for both tasks	First and second phases, pooled data: Longer than present tube
3-year-olds	6/18 (33%)	8/18 (44%)	9/18 (50%)	9/18 (50%)
4-year-olds	10/21 (48%)	11/21 (52%)	13/21 (62%)	18/21 (86%)
5-year-olds	8/19 (42%)	16/19 (84%)	16/19 (84%)	18/19 (95%)
6-year-olds	6/18 (33%)	11/18 (61%)	13/18 (72%)	16/18 (89%)
7-year-olds	9/16 (56%)	15/16 (94%)	13/16 (81%)	15/16 (94%)
Total	39/92 (42%)	61/92 (66%)	64/92 (70%)	76/92 (83%)

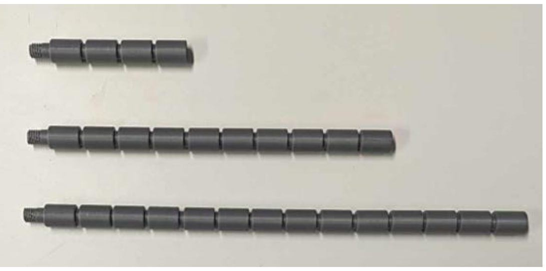

Figure 3. *Top:* Minimum tool length (2 pieces) required for the present-oriented task. *Middle:* tool (5 pieces) of greater length than present-oriented task. *Bottom:* tool length (7 pieces) required to solve both tasks. *Note:* a single 'piece' consisted of two pre-joined dowels.

Age comparisons. The overall tool length was significantly and positively associated with age, $r_s(90)=0.241$, $p=.021$. There was no association between age and making a tool of sufficient length to solve both tasks, $r_{pb}(90)=.08$, p=.460. However, there was a significant positive association between age and making a tool longer than the tube in the present-oriented task, $r_{pb}(90)=.30$, $p=.004$.

First and second tool construction phases (pooled data)

Tool length. The descriptive statistics in Table 1 reflect the lengths of tool made by all children pooled across the first and second (if necessary) phases (*M*=6.17 pieces, *SD*=1.45). Across both phases, 64 children (70%) made a tool of sufficient length to solve both tasks. Twelve others (13%) made a tool longer than the tube used in the present-oriented task. Therefore, overall, 83% of children made a tool of greater length than the tube in the present-oriented task, demonstrating some capacity to think about future utility.

Age Comparisons. Again, there was a significant positive association between overall tool length and age, $r_s(90)=0.26$, $p=.013$. The correlation between age and making a tool of sufficient length to solve both tasks similarly did not reach significance, $r_{pb}(90)=.19$, $p=.065$. However, age was again significantly associated with constructing a tool longer than the tube in the present-oriented task, $r_{pb}(90)=.32$, $p=.002$.

Forked tube task

Three children were missing data for the forked tube task. Of the 89 children who provided data (see Table 2), 63 (71%) covered both exits on the first trial. Correlations revealed that as age increased, children were more likely to cover both exits, $r_{pb}(87)=.35$, $p=.001$. The proportion of trials on which children covered both exits (M=72.75%, SD = 40.94%) was also positively associated with age, such that as age increased children were more likely to cover both exits across a greater proportion of trials, $r_s(87)=0.39$, $p<.001$.

Table 2. First trial performance and mean performance across trials on the forked-tube task.

Age group	First trial	Across trials
3-year-olds	7/17 (41%)	47.06%
4-year-olds	14/22 (64%)	64.77%
5-year-olds	14/18 (78%)	78.70%
6-year-olds	14/17 (82%)	84.31%
7-year-olds	14/15 (93%)	93.33%
Total	63/89 (71%)	72.75%

Tool length and forked tube performance comparisons

First tool construction phase. Children's overall tool length positively correlated with performance on both forked tube measures, as did children's propensity to construct a tool longer than the present-oriented tube, all $r > .25$, $p < .05$ (see Table 3). However, children's propensity to construct a tool of sufficient length to solve both tasks did not correlate with either forked-tube task measure, both, $r < .15$, $p > .05$. Pearson's age-partialled correlations, between all tool length measures and both forked-tube performance measures were also not significant, all $r_p < .20$, $p > .05$ (see Table 3).

First and second tool construction phases (pooled data). There were significant positive correlations between all tool length measures and both forked-tube performance measures, all $r > .30$, $p < .01$ (see Table 3). Critically, age-partialled correlations between all pooled tool length measures and both forked tube measures were also significant, all $r > .26$, $p < .05$ (see Table 3).

Table 3. Correlation analyses between both forked-tube task measures and all tool length measures.

Tool construction performance	Forked-tube performance			
	First trial		Across trials	
	r	r_p	r	r_p
First phase				
Continuous length	[b] .27*	[d] .19	[a] .30**	[d] .19
Sufficient for both tasks	[c] .13	[d] .11	[b] .14	[d] .12
Longer than present tube	[c] .27*	[d] .19	[b] .27*	[d] .19
First and second phases, pooled data				
Continuous length	[b] .42***	[d] .35***	[a] .38***	[d] .34**
Sufficient for both tasks	[c] .33**	[d] .28**	[b] .31**	[d] .26*
Longer than present tube	[c] .42***	[d] .35***	[b] .39**	[d] .32**

**p <.05, **p < .01, ***p < .001.*

[a] Spearman's rho, [b] Point-biserial correlation, [c] Phi coefficient, [d] Pearson's partial correlation (age-partialled)

Discussion

The results of Experiment Two revealed clear improvements with age in children's ability to construct a tool with future utility in mind. These age effects were consistently evident for two of the three measures of children's tool construction: overall tool length and propensity to make a tool longer than the present-oriented task. The age effect was not evident for the other measure – propensity to make a tool long enough to solve both tasks – but this may be due to other factors such as the possibility that some younger children simply enjoyed connecting all dowel pieces together without any consideration of either present or future utility.

Intriguingly, there were also consistent age-partialled correlations between the pooled tool construction measures and children's performance on the forked tube task. These associations suggest that both tasks draw on a common underlying capacity to imagine and prepare for multiple possibilities. That is, children must consider and prepare for mutually exclusive possibilities as measured by the forked tube task (i.e., the ball can only fall in one place), and think about mutually inclusive possibilities as required in the tool construction task (i.e., a long enough tool can be used to solve either or both problems). And, as preparing for more than one possibility is an essential step in foresight development (Redshaw & Suddendorf, 2016), these associations suggest that children's growing capacity for future-directed thinking may indeed be connected to recognising the utility of a solution and, thus, innovation.

General Discussion

The results from Experiment One showed that while 3- and 4-year-old children struggled to recognise the future utility of a solution to the hook task, 5-year-olds were able to do so above what was expected by chance. However, when given a more simplistic problem-solving task, as in our Experiment Two, 5-year-olds, and even many 4-year-olds, were able to recognise the utility of a potential solution by building it in preparation for a future problem. This pattern of results suggests that, despite young children's struggle to innovate when assessed by their ability to create a new solution to a present problem (Beck et al., 2011; Breyel & Pauen, 2021; Burdett & Ronfard, 2023; Neldner et al., 2017; Voight et al., 2017), they appear to possess the capacity to recognise a solution, and even to *recognise its future utility* – which is a fundamental component of innovation critical to attaining ongoing benefits..

The pattern of results found in Experiment Two neatly maps onto the broader literature on the emergence of foresight, which emphasises a key developmental transition during the fourth year (e.g., Suddendorf et al., 2022). One possibility is that the inclusion of the second construction phase reduced the number of false negatives in the data, such that 4-year-olds' initial experience with using the shorter tool on the present problem prompted them to recognise that this tool would not be long enough to solve the future problem. Accordingly, it is possible that 4-year-olds would similarly improve their performance if given a second opportunity at the future-oriented hook task we devised for Experiment One.

Nonetheless, it is likely that there were also some false positives in Experiment Two. Firstly, some children (especially 3-year-olds) may have just enjoyed the act of building and, without considering future utility, were intrinsically motivated to construct a longer tool. To address this, future studies could include a control condition where children need only build a tool to solve the shorter, present-oriented task to determine a baseline tool length, or provide children with superfluous resources or introduce a time or resource cost to see if they are indeed selective in their tool-making decisions. Secondly, given the close temporal and spatial proximity of the tasks – the red mat and the box covering the longer task were in view while children were constructing their tool – children's success on both tasks may not reflect their capacity to create solutions with the longer-term future in mind. In the real world, creating new technologies is often a painstaking process which can take years of planning, prototype testing, and rounds of revision before being put to use. Future research may therefore want to increase the temporal and spatial proximity between the tasks by including extra filler activities or spacing the tasks across two rooms rather than across adjacent mats.

Despite these limitations, our experiments introduce a fresh approach to exploring children's capacity for innovation. Integrating paradigms across the foresight and innovation literatures has herein allowed us to show that young children can recognise and build a solution for a future problem. Future research might wish to adopt this integrated approach to instead examine the emergence of other expressions of innovation, such as retaining a tool for repeated use, refining it for more efficient use, and sharing it with others for broader use (Suddendorf et al., 2018). Indeed, the relationship between children's performance on the tool construction and forked tube tasks in Experiment Two supports the idea that innovation, at least, is just one behavioural manifestation of our more general foresight capacities (Suddendorf et al., 2022). Future research may wish to further explore this link to determine whether children's basic innovative behaviours are related to other components of foresight such as executive function, metacognition, and prospective memory (Suddendorf & Redshaw, 2013).

In conclusion, foresight is an essential ingredient to our capacity for innovation but has thus far been overlooked in the developmental innovation literature. Even if young children lack the motor skills or creativity to manufacture a novel tool, this need not mean that they cannot recognise a solution to a future problem when they see it. Thus, young children do indeed show a capacity for innovation – at least in the sense that they can recognise future utility.

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