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Abstract

Children easily learn about tools from others, but have difficulty innovating tools independently. The current studies combine these research areas and explore the social influences on children's ability to innovate their own tools from already modified materials. In Experiment 1 (N = 104) 5- to- 8-year-olds were unaffected by statements of designer's intentions. Children were drawn to using modified materials in all conditions, but did not alter them to make functional tools. Experiment 2 (N = 163) found that children were not drawn to modified materials simply because they look made. Results are discussed in relation to executive function, scale errors, and task pragmatics. Overall, we conclude that the presence of modified materials negatively affects children's innovation of tools.

Key words: tool innovation; problem solving; social learning; design stance; scale error.

Is tool modification more difficult than innovation?

Children are experts at learning about tools from other children and adults (see Hopper, Flynn, Wood & Whiten, 2010; Simpson & Riggs, 2011, respectively). From a young age children's tool behaviors develop by watching others select (Casler & Kelemen, 2007), use (Nielsen, 2006; McGuigan &Whiten, 2009) and manufacture (Beck, Apperly, Chappell, Guthrie & Cutting, 2011; Cutting, Apperly & Beck, 2011) tools. In contrast, children's ability to independently innovate simple tools (i.e. make tools to solve a novel problem or make a novel tool to solve a problem) is surprisingly late developing. However, studies that have examined children's innovative tool making have largely focussed on their interactions with new (unmodified) materials (such as unbent pipecleaners that need to be used to make a novel tool). Whereas, in everyday life children are likely to encounter many more modified materials, including premade tools. Furthermore, recent emphasis on the social aspects of innovation (Carr, Kendall, & Flynn, 2016; Muthukrishna & Henrich, 2016) highlights the fact that in human history innovations are not always the result of an individual working independently (independent innovation). Instead, human innovations often result from generations of individuals improving on earlier items or behaviour to achieve end points that would not have been possible for a single individual. Carr et al. (2016) argue that previous accounts of children's innovation fail to include opportunities for innovation by modification. Extensive research has shown that children (Defeyter, Avons & German, 2007; Matan & Carey, 2001) and adults (Chaigneau, Castillo & Martínez, 2008) treat artifacts as having been made by someone for a particular purpose. Being influenced by the Designer's Intended Function is likely to affect children's ability to modify artifacts for a new purpose. In this paper we explore this social aspect of tool innovation exploring whether children find innovation by modification challenging, as they do independent innovation.

There is consensus that young children (certainly under 5 but possibly until they are 8), struggle to innovate novel tools to solve problems independently. On a task requiring children to retrieve a bucket from a tall narrow tube, the majority of children do not make the simple hook tool needed until around age 8 (Beck et al., 2011). Young children's (up to 5) difficulty with tool innovation has been shown to extend to other materials (Beck et al., 2014), different tasks (e.g. looping a piece of flexible wood to drag a platform, Tennie, Call, & Tomasello, 2009), and in informal as well as formal contexts (Sheridan, Konopasky, Kirkwood, & Defeyter, 2016 although only for 3 and 4 year olds). Children's difficulty with tool innovation is also not restricted to WEIRD populations; similar success rates on the hook-innovation task have been found in other cultures (Nielsen, Tomaselli, Mushin & Whiten, 2014; Frick, Clément & Gruber, 2017).

While these studies presented children with unmodified materials with which to make tools, in real life we commonly encounter pre-made tools and modified materials; probably more so than unmodified materials (n.b. we use unmodified here to refer to materials such as pipecleaners which, although manufactured, can be encountered in an 'original' state before being bent). Yet, we do not know how encountering modified materials may affect children's problem solving. One possibility is that modified materials may act as a clue or support for the solver. They may take a similar form to the solution required, e.g. a hook, or may be the wrong form but provide some insight into the mechanism required for transformation, e.g. I must bend the pipecleaner. Alternatively, modified materials may hinder the problem-solving process. We live in an extremely social world, and as such we interpret that people show or tell us things for a reason (Heyes, 2016). A situation where an adult gives a child materials may be interpreted as a pedagogical interaction, and the child may assume that the adult was offering a suitable tool for the task. We already know that children are sensitive to pedagogical cues from a very young age (Csibra & Gergely, 2009). This may be particularly true in situations where materials have been modified. The presence of a purposefully modified material may be interpreted as the correct solution to a problem and therefore prevent a solver from generating their own solutions. The influential nature of pedagogical situations has been demonstrated in exploration tasks where children engaged in lower levels of object exploration compared to non-pedagogical situations (Bonawitz et al., 2011).

Literature on children's tool-using seems to support both possibilities: that pre-made tools could be advantageous or hindering for children's tool innovation. In studies of hook-making where children have access to modified materials in the form of pre-made functional hooks they tend to perform relatively well. If shown how to make a hook, almost all children then go on to modify a new pipecleaner appropriately (Beck et al., 2011). Children who are given a pre-made hook to solve the task also perform better when later they are given unmodified materials to make a tool themselves (Whalley, Cutting, & Beck, 2017). However, in these studies the pre-made tools children see or use are suitable for the task at hand. The child needs only to reproduce the tool. We currently lack studies of children's ability to innovate by modification (Carr et al., 2016), for example when given a pre-made tool that is relevant but not currently functional. This is important, because recreating a tool you have already seen indicates only 'social learning' and there is already much evidence that speaks to this. But to demonstrate innovation by modification the child must *change* the tool they are presented with and a clear way to motivate this is to present a non-functional tool.

To date only two studies have investigated innovation by modification (Carr, Kendal and Flynn, 2015; Neldner, Mushin & Nielsen, 2017). Neldner and colleagues (2017) presented three- to five-year-old children with the hook-innovation task described above (Beck et al., 2011). They compared performance on the original version of the task, presenting participants with a straight pipecleaner and a distracter item, with a second condition in which participants were presented with a non-functional hook tool (the tool had a correctly sized hook at one end but was curled at the other end making it non-functional for the task). Children were nine times more likely to innovate a successful tool in this new condition where the hook affordance was visible. Neldner and colleagues suggest that the visual affordance of the hook tool reduced the cognitive load of the task.

Carr et al. (2015) presented four- to- nine-year-old children with a puzzle box, the children then witnessed eight demonstrations of how to retrieve a reward. The efficacy of these solutions varied (0%, 25%, 50% or 100%). Children then attempted the puzzle box for themselves. Imitation and innovations were recorded. As expected, lower levels of solution efficacy lead to increased innovations. However, innovations were rare with only 12.4% of children innovating a novel solution. This study shows that in a highly social situation children are reluctant to deviate from the modelled behaviour they have seen and innovate successful solutions for themselves. The current studies explore different forms of innovation by modification than those conducted by Carr et al. (2015) and Neldner et al. (2017). In contrast to the live demonstrations provided in Carr et al. (2015), the current studies reduce the social context by presenting tools as having been made by a person not present. In contrast to Neldner et al. (2017) the presented tools, although relevant to the task, do not have a functional component.

While one might assume that using a modified tool as starting point for innovating a tool might be helpful (Neldner et al., 2017), another literature suggests that the influence of pre-made tools may not be so positive. From a young age, children have a desire to learn about objects and, in particular, their functions, e.g. children ask more questions about an object when they have not been told its function (Kemler Nelson, Egan, & Holt, 2004). It is clearly beneficial to learn object functions as it allows people to be efficient in their use of objects (Casler & Kelemen, 2005). For example, imagine having to figure out how to complete every task you are confronted with throughout the day, rather than simply knowing that a brush will tidy your hair and a spoon will get the food from the bowl to your mouth. Research into our fascination with function has focused on ideas about 'proper' functions. For example, we can use a hammer to hold down a pile of papers but we know that a hammer is really for banging in nails (Chaigneau, Puebla & Canessa, 2016). In general these so-called 'proper' functions correspond to the intentions of the original designer of an object. The finding that people tend to categorise objects in line with the original designer's intended function is termed 'design stance' (Dennett, 1987). Research suggests that people who hold a design stance determine the function of an object based on its original intended function rather than its appearance or current use (German & Johnson, 2002). While some studies have directly tested for the existence of design stance (Matan & Carey, 2001; Rips 1989), most studies with children have focused on the age at which they think artifacts have specific functions (Casler & Kelemen, 2005; German, Truxaw, & Defeyter, 2007).

Some researchers claim that object function categories are formed from a young age (Asher & Kemler Nelson, 2008; Kelemen, 1999). Casler and Kelemen (2005) have suggested that after seeing an object used for a certain task, children as young as two-and-a-half deem that it is 'for' that task and choose to use it themselves, even if other functional alternatives are available. In contrast, children reject that object for another task even if it is a viable functional option. Casler and Kelemen argue this demonstrates the beginnings of design stance in children as young as two. Although, the evidence only speaks to children's appreciation of the 'proper' function, not whether they hold beliefs about its intended function.

Other researchers argue that these biases do not develop until later. There is general consensus in the literature that preference to categorise novel objects based on the first demonstrated function develops around age 6 and then persists into adulthood (see Chaigneau et al., 2016). German and colleagues (2007) argue that children under the age of 6 determine function based on any goal they observe from a demonstrator. In keeping with this, younger children have been shown to be much more flexible in their use of objects than older children. Functional fixedness refers to the observation that once they are shown that an object is *for* a particular task, older children then find it extremely difficult to spontaneously use that object for an alternative function. Defeyter and German (2003) presented children with a task which required using a known artefact in a novel manner to solve a problem. Following priming of the typical function of the artefact, 5-year-olds were much faster at solving the task than 7-year-olds. Further evidence that children are unaffected by the original demonstrated functions of objects until age 6 comes from a variety of tasks, including function judgement (German & Johnson, 2002), categorization (Defeyter, Hearing, & German, 2009; Matan & Carey, 2001), divergent thinking (Defeyter et al., 2007) and problem solving (German & Defeyter, 2000; Defeyter & German, 2003). These studies suggest that the younger children were immune to the knowledge of the object's designed function when innovating and this resulted in *improved* performance.

The onset of children's preference for first demonstrated functions corresponds with the age at which an understanding about the ownership of ideas develops (Olson & Shaw, 2011). A recent review of the design stance literature suggests that the normative account of ownership offers the best explanation for children's behaviour. This account posits that by creating an artifact the designer is the owner of the idea, meaning they have the right to determine the category of the object (Chaigneau et al., 2016).

It is possible that children's ability to innovate tools by modification may be hindered by their bias to use a tool that they think already has a function, especially if they think it has been designed for the job (and therefore they should not change it). Note that if we take Casler and Keleman's evidence as showing that children as young as 2 and a half years identify the 'proper' functions of objects then even very young children may be negatively influenced by the presence of the pre-made tool. If Casler and Keleman's interpretation of their evidence is correct and shows that children at this age are starting to hold a design stance, then we might expect to see children's performance being influenced by information about design.

In sum, there are diverging predictions when we consider how a pre-made (but non-functional) tool may influence children's innovation. Evidence from previous tool-making studies shows that the presence of certain pre-made (functional) tools results in improved performance and thus children may benefit from the information provided by a pre-made non-functional tool. Furthermore, the observation that humans tend to innovate collectively by modification (see Caldwell, 2018, and Muthukrishna & Henrich, 2016), might induce us to think that social innovation might be earlier developing than asocial, independent innovation. Thus, when they encounter pre-made non-functional tools, children may be supported in making a novel functional tool, either from new materials or by adapting the pre-made tool. On the other hand, the functional fixedness and pedagogy literatures suggest that children may make inferences about a pre-made tool that could result in a tendency *not* to adapt it. These are the possibilities that we seek to explore in our studies. In Experiment 1 we investigated the relation between designer's intended function and tool innovation by manipulating the information given to children about the artifacts. We build on Experiment 1's findings in Experiment 2 by further investigating the influence of different modified materials on children's subsequent tool innovation.

Experiment 1

In Experiment 1 we presented children with the task described above (Beck et al., 2011), requiring them to retrieve a bucket from a tall narrow tube by making and using a hook tool. Children were given a pipecleaner that had been made into a large hook shape and an unmodified straight pipecleaner. The large hook was the right kind of tool needed to complete the task, but it was non-functional due to being too big. It fitted into the apparatus, but was too large to be manoeuvred under the handle of the bucket. Children therefore either needed to modify the oversize hook pipecleaner to make it functional, or to make a functional hook from the straight pipecleaner. This is in contrast to Neldner et al. (2017) who required children to act directly upon the modified material, modifying the non-functional curl in order to utilise the functional hooked part of the tool. To investigate the effect that designer's intentions and information about proper functions may have on children's willingness and ability to modify previously made tools, children were told that the oversize hook had either been made for a similar task, a different task, or had accidentally bent in the experimenter's bag.

If children believe objects to have proper functions based on designer's intentions then we would expect to see differences between the three conditions. In the 'similar task' condition children may prefer to adapt an already made tool if they believe it was made for the task. In this case we would expect children to have a preference for choosing the large hook over the straight pipecleaner, and then modifying it into a functional tool. Alternatively, children may choose the large hook and then become fixed on using this designed tool and not modify it to make it functional. In the 'different task' condition, the literature suggests that children should disregard the oversize hook as it is made for something else, they should therefore be more likely to choose the straight pipecleaner. In the 'accidental' condition children should be just as likely to choose either pipecleaner, as neither has been primed for being for any particular task. Alternatively, there may be a slight preference for the straight pipecleaner as it is not 'damaged'.

Method

Participants

The participants were 57 children aged 5- to 6-years (30 boys), mean = 5 years 9 months (5;9), range = 5;3 – 6;3, and 47 children aged 7- to 8-years (21 boys), mean = 7;9, range = 7;3 – 8;3, from two primary schools serving low and middle income families, in a large UK city. The ethnic composition of the sample was 75% Caucasian, 20% Asian, and 5% Black. Equal proportions of children from each school were present in each age group.

Materials

The apparatus for the tool-innovation task consisted of a clear plastic tube (length = 22cm, width of opening = 4cm) attached vertically to a cardboard base (length = 35cm, width = 21cm), a bucket containing a sticker, white, black, and red straight pipecleaners (length = 29cm). Half of the pipecleaners were presented straight and half were bent into large hook shapes (see Figure 1). A small clock was used to time the task.

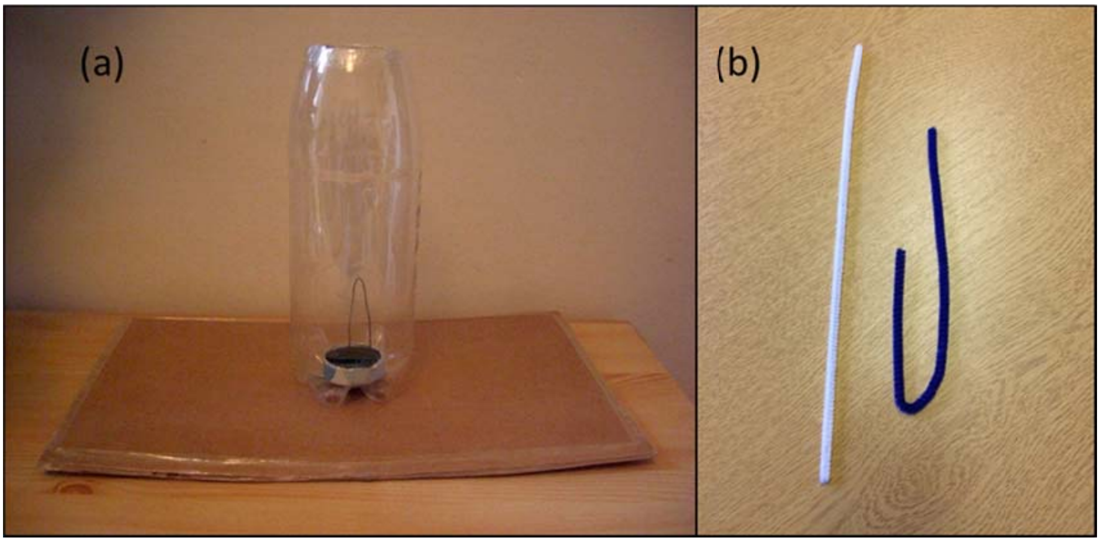

Figure 1. *Apparatus (a) and materials (b) for Experiment 1.*

Procedure

Before testing, children were instructed by their class teacher not to tell other children how to play the games they would be playing with the experimenter to ensure they would be a nice surprise for everyone. All participants were tested by a female experimenter in a quiet area just outside the main classroom. The child and experimenter sat at right angles to each other at the corner of a table. Children were alternately allocated to one of three conditions: Similar, Different or Accidental.

For all conditions children were asked whether they could see the sticker in the bucket, and were told that if they could get the bucket out then they would win the sticker inside it. The oversize hooked pipecleaner and a straight pipecleaner were then placed on the table in front of the apparatus (position counterbalanced) and the children were told 'here are some things that can help you to get the sticker'. The accompanying descriptions varied depending on condition. In the similar condition children were told 'this one was made by someone to solve a task a bit like this'. In the different condition children were told the bent pipecleaner was 'made by someone for a different task' and in the accidental condition they were told that it had 'accidentally bent in my bag'. The straight pipecleaner was always presented second by saying 'here's a new one'.

Children were given one minute to attempt to solve the task in the initial innovation stage of the experiment. No feedback was given, but children were given neutral prompts if required. Examples of prompts used include 'Can you think how you might be able to get the sticker out?' and 'Maybe you could use these things to help you.' If, after one minute, the child had not retrieved the sticker, they were encouraged by the experimenter to put down the materials they were using. Children then proceeded to the demonstration phases of the experiment. With the materials remaining in view of the participant, the experimenter then said 'look at this,' and brought out a readymade red pipecleaner hook of the appropriate size to solve the task for the child to view (target-tool demonstration[1]). The children were again encouraged to retrieve the sticker using their own materials. If after 30 seconds the child had still not retrieved the sticker, they were told to put down their materials. With their materials remaining in view as before, the experimenter said ‘watch this’ and taking her own red straight pipecleaner, held in the middle, bent one end to form a functional hook (tool-creation demonstration). Children were again encouraged to use their own materials to retrieve the sticker. If children were still not successful in making the required hook tool they were given verbal prompts such as ‘Did you see what I did with mine?’ and then ‘Can you do that?’ If children did not succeed on the task independently they were helped to retrieve the bucket and were rewarded with the sticker.

Coding

Children’s behaviours during the innovation task were coded live by the first author. The coding system included which material was touched, picked up and entered into the tube, and how and which materials were modified. Children were recorded as successful on the task if they made a hook tool and used it to retrieve the bucket from the tube within the one minute timeframe.

Results and discussion

The sample was first split by gender to investigate possible sex differences in behaviors. Regarding initial behaviors, there was no overall difference in the material selected first by children, $\chi 2$ (1, N = 104) = 0.247, p = .619, φ = -0.049. This was also the case when we analyzed the conditions and age groups separately (lowest p = .319). There was also no difference in rates of perseveration with one material (lowest p = .107). There was no

[1] This demonstration could be described as ‘emulation’ (c.f. imitation). We use the terms target-tool and tool-creation demonstration following Cutting, Apperly, Chappell, & Beck (2014) because our focus is on problem solving by individuals, rather than cultural transmission.

overall effect of gender on success (making a functional tool and retrieving the bucket) $\chi 2$ (1, N = 104) = 0.574, $p = .449$, $\varphi = 0.074$. Younger boys were more successful than girls in the similar condition, FET, $p = .049$, $\varphi = -0.514$, but due to the low overall success rate in this condition (3 out of 20) we will not pursue this difference further. There were no further gender differences in any condition for either age group (lowest $p = .093$). Note that we have also run multiple tests to investigate gender which increases the likelihood of this one significant effect being a false positive There was no difference in the material used to make the successful tool (modified or straight pipecleaner. Lowest $p = .132$). Data were combined across gender for subsequent analyses. The presented analyses will focus on the innovation stage of testing. Success rates for the demonstration phases are presented in the tables but as they are not relevant to the main research question, they will not be discussed.

Choice of materials

Children's specific behaviours during the task were analyzed, in particular which materials they chose to use first and which materials successful children used to solve the task.

There were no differences between conditions (similar, different, accidental) as to which material children chose to use first when we considered both age groups combined, χ^2 (2, N = 104) = 3.892, $p = .143$, $\varphi = 0.193$, or independently, 5- to- 6-year-olds, χ^2 (2, N = 56) = 2.330, $p = .312$, $\varphi = 0.204$; 7- to- 8-year-olds, FET, $p = .264$, $\varphi = 0.236$. When combining first choices across all three conditions, binomial tests found that overall children tended to choose the oversize hook rather than the straight pipecleaner ($p = .004$). There was a difference in behaviours between the older and younger children, χ^2 (1, N = 104) = 4.351, $p = .037$, $\varphi = -0.205$. The preference in choosing the hooked pipecleaner was driven by the older children (binomial, $p < .001$). Younger children were at chance for their first choice of materials (binomial, *p* = .504). When children successfully made a hook tool pre-demonstration, they tended to do so with the straight pipecleaner, *p* = .052. The majority of children used both materials to attempt to solve the task (70%), showing little perseveration with one material. There was no difference in perseveration rates between conditions for both age groups combined, $\chi2$ (2, N = 104) = 1.434, *p* = .488, φ = 0.117 , or separately, 5- to- 6-year-olds, $\chi2$ (2, N = 57) = 1.703, p = .427, φ = 0.173; 7- to- 8-year-olds, $\chi2$ (2, N = 47) = .212, *p* = .899, φ =0.067. Younger children (39%) were however more likely to persist with one material than older children (17%), $\chi2$ (1, N = 104) = 5.842, *p* = .016, φ = -0.237. Only 4 children (one younger and three older) modified the pipecleaners before first entry into the tube. In all cases they modified the straight pipecleaner into a hook.

Table 1. *Material choice and success rates in Experiment 1.*

			First material choice[a]				Success (%)			
Age Group	Condition	N	Oversize hook	Straight	Persisted with first choice (%)	Modified materials pre-demo	Before demonstration	After target tool	After tool-creation	Fail
5 to 6	Similar	20	11	8	11 (55%)	3	3 (15%)	4 (20%)	5 (25%)	8 (40%)
	Different	18	12	6	6 (33%)	2	1 (6%)	4 (22%)	7 (39%)	6 (33%)
	Accident	19	8	11	6 (32%)	8	3 (16%)	5 (26%)	1 (5%)	10 (53%)
7 to 8	Similar	16	14	2	3 (19%)	10	6 (38%)	8 (50%)	1 (6%)	1 (6%)
	Different	15	11	4	3 (20%)	8	5 (33%)	6 (40%)	4 (27%)	0 (0%)
	Accident	16	10	6	3 (19%)	6	4 (25%)	8 (50%)	3 (19%)	1 (6%)

Note: [a]Excluding one child who picked up both simultaneously.

Successful tool innovation

Success levels in the innovation stage were poor overall (see Table 1). Only 22 children (21%) successfully innovated a hook tool. Older children were more successful than younger children, χ^2 (1, N = 104) = .5.954, p = .015, φ = 0.239. There were no differences in success levels between the three conditions, χ^2 (2, N = 104) = .522, p = .770, φ = 0.071. The lack of difference between conditions remained when the two age groups were analysed independently, 5- to- 6-year-olds, Fisher's Exact Test (FET), p = .574, φ = 0.140; 7- to- 8-year-olds, FET, p = .742, φ = 0.113. It is possible that the lack of effect we observed was the result of a relatively small sample size, able only to detect large effect sizes. While future research could use larger samples to test for more subtle effects, our study shows that being provided with information about the designer's intention did not have a major effect on children's innovation success.

One possibility, suggested by an anonymous reviewer, is that the lack of difference between conditions arose because children did not pay attention to the information they were given about the pre-made hook. Future studies could include check questions to confirm this information was retained, but we think it likely that this would have been the case as the fast mapping literature shows that children from 3 years old use facts that they have been told about an object. For example, Kalashnikova, Mattock, and Monaghan (2014) showed children two novel objects and gave them a fact about one of them, e.g. "My dog likes to play with this." When children were then asked which of the two objects fit a different description, e.g. "My uncle gave this to me" participants systematically chose the other object. Holland, Mather, Simpson, and Riggs (2016) confirmed that children could recall this information: having heard incidentally that "my uncle gave it to me" just once during an interaction with ten objects, they were then able to pick out the target object in a comprehension task.

Although only 22 children successfully innovated a hook tool, an additional 15 children modified the materials they were given in some way (see Table 1). Children may have understood that the task required them to modify the materials, but were unable to correctly execute the required actions.

Experiment 1 found no difference in children's ability to innovate a tool depending on whether they were told that modified materials had been made for a similar task, a different task, or were accidentally bent. However, the results from Experiment 1 bring forward an interesting question about children's interactions with the tools they encounter. The success rates from this experiment appear to be lower than those previously reported (see Beck et al., 2011 and Cutting et al., 2011), although as we did not include a baseline condition in Experiment 1 we cannot be sure of this. The main difference between this procedure and previous studies was the presence of the oversize hook. In Experiment 2, we went on to effect the potentially negative influence of a pre-made tool.

Experiment 2

Rather than acting as a clue to help children solve the hook innovation task, the presence of the oversize hook in Experiment 1 may have hindered children. Children had a tendency to choose and use the hook first, but did not go on to modify it into a functional tool. We propose two potential explanations for why children choose to attempt the task with an oversize hook rather than a straight pipecleaner; 1) It is recognized as the right sort of tool needed for the task and then children become fixed upon it and do not modify, or, 2) Children are drawn to it because it looks different from a prototypical straight pipecleaner. Children may be drawn to the hook because it looks *made* (i.e. someone has fashioned it into a shape) but have no real understanding that the task requires a hook, or they may be drawn to it because it looks more interesting than the straight pipecleaner.

In Experiment 2, we aimed to disentangle these alternative explanations by testing children in one of three conditions. Children were given the tube apparatus and asked to retrieve the bucket and sticker as in Experiment 1. Children were either given the oversize hook pipecleaner and a straight pipecleaner as before (oversize hook condition), or were given a pipecleaner with a twist in the middle and a straight pipecleaner (twist condition). We also included a baseline condition in which children were given two straight pipecleaners.

Similar to the hooked pipecleaner, the twisted pipecleaner looked made and more interesting than the accompanying straight pipecleaner. If children were previously choosing the hooked pipecleaner simply because it looked different, with no understanding that the task required a hook, then we would expect to see similar patterns of behavior in the oversize hook and twist conditions. If children understand that the task requires some sort of hook, then we would expect to see differences in behaviours between the oversize hook and twist conditions. The baseline condition allowed us to measure whether performance in the oversize hook and twist conditions was enhanced or hindered compared to standard performance on this innovation task.

Method

Participants

The participants were 80 children aged 5- to 6-years (41 boys), mean = 5; 11, range = 5; 5 – 6; 5, and 83 children aged 7- to 8-years (39 boys), mean = 7; 11, range = 7; 5-8; 5, from two primary schools serving low to middle income families, in a large UK city. The ethnic composition of the sample was 80% Caucasian, 15% Asian, and 5% Black. Equal proportions of children from each school were present in each age group. None of the children participated in Experiment 1.

Materials

New task apparatus was used in Experiment 2. The sturdier design was engineered for a separate study in which children were left alone with the apparatus. The apparatus for the tool-innovation task consisted of a clear plastic tube (length = 29 cm, width of opening = 4cm) attached vertically to a white base (54cm square) and a bucket containing a sticker. White pipecleaners (length = 29cm) were used for all materials presented to children. These were either straight and unmodified, bent into large hook shape or twisted in the middle (see Figure 2). White pipecleaners were also used by the experimenter for the target-tool and tool-creation demonstrations. A small clock was used to time the task.

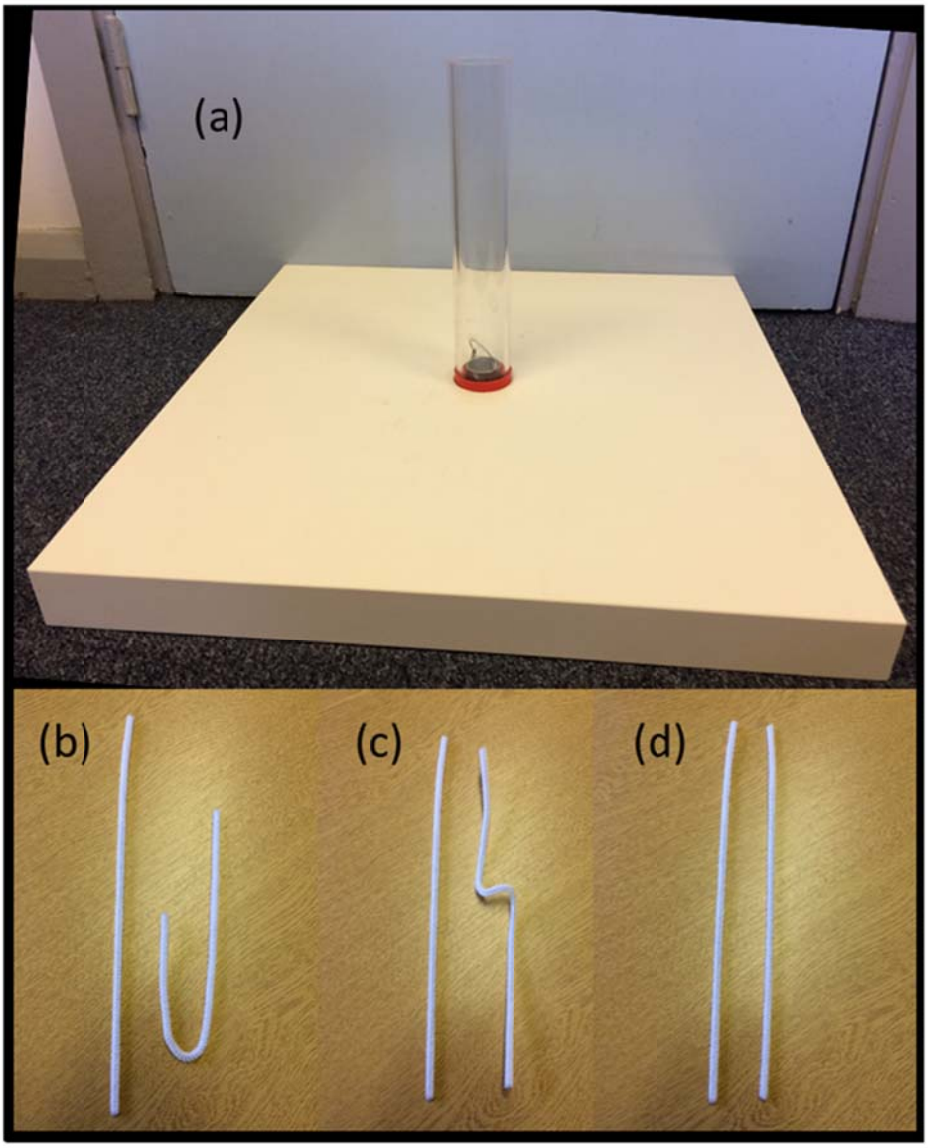

Figure 2. *Apparatus (a) and materials for the oversize hook (b), twist (c) and baseline (d) conditions in Experiment 2.*

Procedure

Experiment 2 followed a similar procedure to Experiment 1. Children were told that they needed to retrieve the bucket from the tube in order to win the sticker. They were then told '*here are some things that can help you*' and presented with the materials corresponding to their condition. An oversize hook and a straight pipecleaner (oversize hook condition), a pipecleaner with a twist in the middle and a straight pipecleaner (twist condition) or two straight pipecleaners (baseline condition). Children were given one minute to try to solve the task. If unsuccessful they followed the same procedure as before, receiving the target-tool demonstration and the tool-creation demonstration if necessary.

Coding

The task was coded live by the first author and second coded live by a research assistant. The new task apparatus used in Experiment 2 unintentionally made the task more difficult for children. As the tube was uniformly 4cm wide rather than getting wider at the bottom there was not much room to manoeuvre the materials. As such any slight bends in the length of the pipecleaner made it quite difficult to move it into the correct position to hook the bucket out. Therefore, if children bent their pipecleaner incorrectly on their first attempt, it was very difficult for them to modify it into a functional tool, despite them having made a correctly-sized hooked end. Due to this, success rates were coded in two ways: *Strict success*, meaning that children made a hook and retrieved the bucket by themselves with no help from the experimenter, and *Success with help*, meaning that children made a correctly-sized hook with the pipecleaner, but needed help from the experimenter in completing the task. This help took the form of manoeuvring the pipecleaner or helping to straighten the length, either by verbal instruction or by physically modifying the pipecleaner. Agreement between coders was 99% for first material entered into the tube, and the success measures.

Results and discussion

The sample was first split by gender to investigate possible sex differences in behaviors. Regarding initial behaviors. there was no overall difference between genders in the material selected and used first in the hook and twist conditions, $\chi 2$ (1, N = 102) = 0.165, p = .685, φ = -0.040. This was also the case when we analyzed the conditions and age groups separately (lowest $p = .374$). There was also no difference in rates of perseveration with one material (lowest $p = .159$). There was no effect of gender on success (making a functional hook, lowest $p = .255$) and no difference in the material used to make the successful tool (modified or straight pipecleaner, (lowest $p = .114$). When examining behaviors in the demonstration phases one gender effect was found. Older boys were better than girls after the tool-creation demonstration in the twist condition, FET, $p = .015$, $\varphi = -0.833$. As the main focus of this experiment was children's initial tool choices and success levels in the innovation phase, and because we had run multiple tests which increases the likelihood of this being a false positive, we will not discuss this finding further this paper.

Choice of materials

Table 2 shows which material children chose and used first when presented with the task. Excluding children who picked up both materials (n = 6), for both age groups there was a significant difference between the oversize hooks and twist conditions in the frequency of choosing the straight pipecleaner (5- to- 6-year-olds, $p = .017$, 7- to- 8-year-olds, $p < .001$). Binomial tests show that in both age groups children chose the oversize hook over the straight pipecleaner in the oversize hook condition (5- to- 6-year-olds, $p = .029$, 7- to- 8-year-olds, $p < .001$), but choices were at chance in the twist condition.

When children were successful at making a hook tool they were more likely to do so with the straight pipecleaner than the modified pipecleaners (hook or twist), binomial test, $p = .008$, and this was unaffected by condition, FET, $p = .559$, $\varphi = .200$.

The majority of children used both materials to attempt to solve the task (65%), showing little perseveration with one material. There was no difference in perseveration rates between conditions for both age groups combined, $\chi 2$ (2, N = 161) = 2.297, $p = .317$, $\varphi = 0.119$, or separately, 5- to- 6-year-olds, $\chi 2$ (2, N = 82) = .409, p = .815, $\varphi = 0.224$; 7- to- 8-

year-olds, $\chi2$ (2, N = 79) = 3.952, p = .139, φ = 0.071 . Younger children (44%) were however more likely to persist with one material than older children (35%), $\chi2$ (1, N = 161) = 6.199, p = .013, φ = -0.196. Only 7 children (two younger and five older) modified the pipecleaners before first entry into the tube. In the younger children, one straightened the twisted pipecleaner and one joined the oversize hook and straight pipecleaner together. In the older children, one joined the twisted pipecleaner with the straight pipecleaner and four in the baseline condition immediately bent one of their straight pipecleaners into a hook.

Table 2. *Material choice and success rates in Experiment 2.*

Age Group	Condition	N	First material choice[a] Made	Straight	Persisted with first choice (%)	Modified materials pre-demo	Success (%) Before demonstration No help	Help	After target tool	After tool creation	Fail
5 to 6	Oversize Hook	27	19	7	11 (40%)	2	1 (4%)	0 (0%)	3 (11%)	10 (37%)	13 (48%)
	Twist	27	10	15	9 (33%)	4	1 (4%)	2 (7%)	9 (33%)	6 (22%)	9 (33%)
	Baseline	25			15 (60%)	4	2 (8%)	0 (0%)	11 (44%)	4 (16%)	8 (32%)
7 to 8	Oversize Hook	28	24	3	6 (21%)	11	5 (18%)	2 (7%)	11 (39%)	9 (32%)	1 (4%)
	Twist	28	11	15	8 (29%)	7	3 (11%)	4(14%)	10 (36%)	6 (21%)	5 (18%)
	Baseline	26			7 (27%)	17	9 (35%)	7 (27%)	6 (23%)	4 (15%)	0 (0%)

Note: [a] Excluding children (n = 6) who picked up both simultaneously.

Successful tool innovation

When we examined children's performance using the strict success measure they were extremely poor at the task, with only 21 out of 161(14%) children successfully making a hook tool and retrieving the bucket (see Table 2). Older children were more successful than younger children, $\chi 2$ (1, N = 161) = 8.709, p = .003, φ = 0.233. Using the strict success measure we found no difference between conditions for both age groups combined or independently (lowest p = .078).

When we examined children's performance in the innovation stage using the *Success with help* measure (including children who succeeded following *strict success*), success rates increased to 36 out of 161 (22%). A further 9 children modified materials but did not make the required tool (not included as successful. See Table 2). Older children were more successful at making a hook than younger children, χ^2 (1, N = 161) = 19.479, p = .001, φ = 0.348. There were differences in success rates between conditions for the older children, χ^2 (2, N = 82) = 10.218, p = .006, φ = 0.353. Performance in the oversize hook and twist conditions were identical (7 of 28 correct), children in the baseline condition were more successful than children in either the oversize hooks or twist conditions, χ^2 (1, N = 54) = 7.361, p = .007, φ = 0.369. There were no differences between conditions for the younger children, FET, p = .587, φ = 0.116, where overall success levels were low (6 out of 79).

The lower success rates in the oversize hook and twist conditions in the 7- to- 8- year-olds suggests that the presence of modified materials hinders children's capacity for tool innovation. Closer inspection of children's behaviours shows that there are likely to be different reasons for the poor performance in each of the conditions. In the oversize hook condition children were drawn to using the oversize hook, but rarely went on to modify it into a functional tool. In the twist condition children's material selection was at chance. The difference in behaviours between the two conditions suggests that children are not drawn to the oversize hook simply because it looks different. If children were drawn to the oversize hook due to looking made or more interesting, then we would not have expected to see the differences between conditions that emerged in this experiment. The results suggest that children chose to use the oversize hook tool because they recognised it as the right sort of tool needed for the task. However, children were unlikely to modify this pre-made tool.

General Discussion

The current studies aimed to discover how the presence of modified materials would affect children's ability to innovate tools and consequently to explore children's capacity for innovation by modification. Experiment 1 investigated the effect of designer's intentions on children's tool innovation. Building on this, Experiment 2 investigated whether children were drawn to modified materials and how their presence influenced ability to innovate tools.

In Experiment 1, children aged 5 to 8 were unaffected by whether they were told a material had previously been modified for a similar or different task, or had been accidentally bent. These children may have been unaffected by knowing the designer's intentions because they do not think objects have proper functions (although previous literature suggests that children at this age should possess this bias (Casler & Keleman, 2005) or at least the older children should (Defeyter & German, 2003)). Alternatively, children may have been unaffected by knowing the designer's intentions due to the materials used in the task. Pipecleaners are a well-known craft material that are used for bending into many shapes, this may mean that knowing the intentions of the person who had modified it (the designer) did not affect children adopting new functions. This latter argument may fit with Chaigneau and colleagues' (2016) suggestion that individuals' attribute the Designer Intended Function based on an appreciation of the designer's ownership of the original idea as to how the object should be used. In the case of pipecleaners, even if someone has bent them to have a particular function, this may not override the original designation of them as craft objects. Future studies could explore the potential impact of the design stance further, by using tools that have an unambiguous function that was the original designer's idea. However, while this may explain why no differences were found between conditions, it does not explain why success rates in Experiment 1 were low compared to previous studies (Beck et al., 2011; Nielsen et al., 2014). It appeared that the presence of modified materials hindered tool innovation in some way, although a lack of baseline meant that this direct comparison could not be made. Children in Experiment 1 were drawn to the oversize hook, and attempted to use it to solve the task, but they rarely went on to modify it into a functional tool.

The presence of modified materials hindering tool innovation could still potentially provide support for the existence of some sensitivity to function in the children tested. Even though children were not affected by the information they were given about designer's intentions (i.e. similar, different, accidental), the modified material may have been seen as having been made for a reason. This could explain children's preference for using it. If this were the case, the current studies could provide novel evidence that children infer that premade tools have a proper function and should not be modified such that they cannot be used for this function.

However, this suggestion that children are drawn to modified materials simply because they look made does not fit with the results from Experiment 2. We must infer that children in this experiment chose the oversize hook because they recognized it as the right sort of tool for the task: Children in both age groups selected the oversize hook over the straight pipecleaner as the first tool they entered into the apparatus. In contrast, selection in the twist condition was at chance. This rules out the possibility that children chose the oversize hook simply because it looked made or more interesting, as there are no grounds for thinking the twisted pipecleaner was any less made or interesting. However, it remains possible that children are more familiar with hooks as useful tools rather than the novel twisted pipecleaner. Future research should include additional tasks that use other tools, all equally novel, or that counterbalances which tool is functional for different conditions. This would allow us to rule out that a simple preference for hooks drives the results in Experiment 2.

Perhaps most interesting, the presence of non-functional modified materials in both experiments resulted in low innovation rates (at least for older children). Children in Experiment 1 were given the clue of an oversize hook, yet success levels for innovating a functional hook tool appeared lower than had been observed in previous experiments where no such clue was given but all other aspects of the task were the same (see Beck et al., 2011; Cutting et al., 2011). This finding was confirmed by Experiment 2, where older children who were given the oversize hook performed worse than children in the baseline condition, who did not receive the hook. Despite having a preference to use the oversize hook first in both experiments, children did not go on to modify the material into a functional tool. This interesting finding is, however, limited by the low success rates across all conditions, and could be strengthened by future research introducing modified materials to tasks in which success rates are already high. If success rates are hindered, then this would provide a more stringent test of the effects of the presence of non-functional modified materials[2].

Children's performance was also hindered compared to baseline in the twist condition. However, it is likely that there are different reasons behind this than in the oversize hook condition. In contrast to the oversize hook condition, children were not preferentially drawn to the modified material. They chose the materials at chance levels.

[2] We thank an anonymous reviewer for this suggestion.

The current studies deviate from previous hook-innovation studies in the materials given to participants. In previous studies the most common distracter item was a piece of string (Beck et al., 2011; Cutting et al., 2011) which was quickly established by participants to not be helpful to solve the task. One possible explanation for children's behaviours in the current tasks is that the presentation of two different 'tools' made from the same material, the twisted pipecleaner and a straight pipecleaner or the oversize hook and straight pipecleaner, appears to the children as a closed choice between two solutions. They may interpret the task as being a choice between the two options and presume that one of them must be correct, therefore preventing them from innovating the tool needed. When children are given the two materials, they may combine this information with their own knowledge in order to solve the problem. This explanation could account for the current findings. In the twist condition neither material looks directly useful to solve the problem and so material choice is at chance. In the oversize hook condition, children see the oversize hook and combine this with their pre-existing knowledge of hooks and are drawn to using that material. In contrast to the social factors involved in a design stance explanation, this forced choice interpretation seems to be a much more asocial explanation. However, perhaps children only interpret the task as a choice paradigm due to the underlying social context that the task has been set-up by the experimenter. One way to reduce the chances of this being viewed as a forced choice paradigm would be to include additional conditions with a non-pipecleaner distractor item presented alongside the oversize, twisted or straight pipecleaner.

The main question of interest is why children choose to use the oversize hook, but then fail to adapt it into a functional tool. This observation is important for our understanding of innovation, as it suggests that innovation by modification can also be difficult for young children. One possible reason is that children recognized the oversize hook as the right sort of tool needed and then became fixed on it and were unable to realise that they must modify it to make it functional. Research on executive function suggests that capacity for inhibition and cognitive flexibility are still developing in the children tested in the current studies (5 to 8 years) (Diamond, 2006; Meiran, 1996). It is therefore possible that children in this age range do not have the cognitive flexibility required to inhibit using the hook tool once they realise it is the right sort of tool they need, and then flexibly consider that it may need adapting in some way (although note that other studies suggested that overcoming these demands are not critical in children's performance on the original hook-making task, Beck, Williams, Cutting, Apperly, & Chappell, (2016) and Chappell, Cutting, Apperly, & Beck. (2013)).

This suggestion aligns with findings of a similar task conducted by Neldner and colleagues (2017). Neldner et al. demonstrated increased success when a non-functional tool was visibly affordant for the task (had a hooked end). The authors argued that presenting children with the hook shape reduced cognitive load, increasing innovation. It is possible that by attempting to facilitate innovation with the correct but non-functional tool-shape the current tasks actually increased cognitive load rather than reducing it.

In line with previous research, the current studies found clear improvement with age in children's innovation success (Beck et al., 2011; Nielsen et al., 2014). Younger children solved the task 17.5% (Exp 1) and 5.1% (Exp 2) of the time, whereas older children solved the task 31.9% (Exp 1) and 42.7% (Exp 2). Some differences in material choices were also observed in the different age groups. In Experiment 1 the younger children were at chance for their material selection, whereas older children preferred to use the modified material (oversize hook). This is potentially explained by older children having greater knowledge about the affordances of hooks. However, in Experiment 2 both age groups were above chance for selecting the large hook over the straight pipecleaner. It is unclear why there was this difference, but we could speculate that the procedure in Experiment 2 was simpler without the additional information about designer's intentions and this made it easier for the younger children to focus on the physical aspects of the materials available.

Another explanation for low innovation rates is that children recognized that they needed a hook but failed to realize that the one provided was too big. They may have blamed the failure of the tool to work on their own capabilities (or lack of) rather than the tool being non-functional. This idea is supported by evidence from the younger children in Experiment 2 who were less successful after a target-tool demonstration if they were in the oversize hook condition than in the twist or baseline conditions (see Table 2). After being shown a functional pipecleaner hook children in the oversize hook condition had a tendency to pick up the oversize hook and continue to attempt to retrieve the bucket without any modifications. There are two different potential explanations for children's behaviour. The first explanation for children's failure to modify the pipecleaner is a general one; and may result from children finding it difficult to determine from motor feedback which errors they have caused, and which are not due to their own motor actions but the 'fault' of the tool.

A third possibility is that children fail to realise the size discrepancy between the oversize hook and the target-tool demonstration due to making a scale error. The phenomenon of scale errors was first reported in toddlers aged between 18 and 30 months (DeLoache, Uttal & Rosengren, 2004). A scale error occurs when an individual tries, unsuccessfully, to complete a task with an object which is inappropriately sized. Reported examples include toddlers trying to get inside a small toy car or sit on a small chair intended for a dollhouse. Recent advances in the scale error literature have suggested that children (Casler, Eshleman, Greene & Terziyan, 2010) and adults (Casler, Hoffman & Eshleman, 2014) make scale errors due to a teleofunctional bias. Casler and colleagues argue that our cognitive systems privilege information about function to such an extent that we fail to consider information about size. This suggestion fits with the current findings that children persist with a hook tool even if it is much too large.

It is important to note that whilst addressing important questions about the nature of children's innovative abilities, the current research on children's tool innovation has been limited to very few paradigms (Beck et al., 2011; Cutting et al., 2011; Hanus, Mendes, Tennie & Call, 2011; Nielsen et al., 2014). The methodology used in the paper is consistent with previous hook-innovation tasks, however it has been suggested that the methodology used may be a little strict, with short time limits given to children and tasks presented in highly unnatural settings (Neldner et al., 2017). Whalley et al. (2017) gave children multiple opportunities to innovate a hook tool by giving three trials and found no improvement in success rates. Voigt, Pauen, and Bechtel-Kuehne (2019) gave 5-year-olds 10 minutes to solve the hook-making problem and found that success levels remained very low (although it is important to note that they suggest that other modes of innovating a tool, such as subtracting parts of the original item rather than reshaping it, may prove easier for children). Given the findings of these two studies there is no evidence that the short timeframe given in the current study masked children's innovative ability.

Whatever the specific reasons for children's behaviours in the oversize hook and twist conditions, the results of the current experiments suggest that the presence of modified materials can negatively affect children's ability to innovate tools and thus, that innovation by modification can be challenging for young children. The most likely explanation seems to be that this is due to the social context surrounding the task. Children expect adults to help and teach them, and to be given correct answers. This is most clearly demonstrated in over-imitation studies, where children copy irrelevant actions after observing them acted out by an adult model (Horner & Whiten, 2005; Lyons, Young & Keil, 2007; Nielsen & Tomaselli, 2010). By giving children modified materials we may be setting them up to fail, as they expect the materials they have been given to be the correct answer to the problem. Although children in the current experiments were unaffected by the social context involving the statement of designer's intentions, it appears that children may be affected by social factors brought about by the pragmatics of the task. Our studies only identify one situation in which innovation by modification is challenging. It remains for future research to see if children are able to modify tools when they are presented by a less-esteemed individual (perhaps another child). However, our studies do show that the interplay between social and individual aspects of innovation is complex and children's innovation is not always supported by the presence of social information.

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