The effects of environment and ownership on children’s innovation of tools and tool material selection

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Research indicates that in experimental settings, young children of 3–7 years old are unlikely to devise a simple tool to solve a problem. This series of exploratory studies done in museums in the US and UK explores how environment and ownership of materials may improve children’s ability and inclination for (i) tool material selection and (ii) innovation. The first study takes place in a children’s museum, an environment where children can use tools and materials freely. We replicated a tool innovation task in this environment and found that while 3–4 year olds showed the predicted low levels of innovation rates, 4–7 year olds showed higher rates of innovation than the younger children and than reported in prior studies. The second study explores the effect of whether the experimental materials are owned by the experimenter or the child on tool selection and innovation. Results showed that 5–6 year olds and 6–7 year olds were more likely to select tool material they owned compared to tool material owned by the experimenter, although ownership had no effect on tool innovation. We argue that learning environments supporting tool exploration and invention and conveying ownership over materials may encourage successful tool innovation at earlier ages.

1. Introduction

The ability to use tools, both simple (e.g. mugs, pans) and complex (e.g. computers, mobile phones), is an integral part of everyday human life [1]. Humans are considered to be extremely competent tool users; children as young as 9 months old use a spoon successfully and have the ability to pull or push one object to retrieve another [2–5].

Tool use is not an exclusively human characteristic, but we are unique in our breadth of technology and rate of invention [1,6]. According to the cultural intelligence hypothesis, this is owing to the development of advanced social skills in humans [7,8]. The coevolution of social skills and tool use, starting around 3.3 Ma, enabled the cumulative development of human culture and technology [6,9–12]. The foundation of tool use is the ability to create and invent tools, which evidently performed a vital role in human evolution [6,12,13]. Studying children, whose capabilities are still developing, allows insights into the psychological processes supporting tool-making and the age at which specific tool-making skills develop [14].

Using a similar hook task to the comparative literature, studies have shown that only around half of children by age 8, and very few children under the age of 5, innovate a hook from various materials provided, including pipe cleaners, to successfully retrieve a basket [13–17]. This finding has been found to be consistent cross-culturally, both in WEIRD (Western, Educated, Industrialized, Rich and Democratic) societies and with a remote tribe of South African Bushman, and has been replicated with more simple tasks [13,14,16,18].

Despite this difficulty to innovate, Beck et al. [15] demonstrated that children as young as 4 years old can recognize that a hook is the most functional tool to
solve the problem, readily selecting a hooked pipe cleaner over a straight pipe cleaner. Children as young as 3 years old can manufacture both tools and non-tools (e.g. a rattle) after adult demonstration [13,15–17,19,20]. Therefore, if children appear to have the knowledge to solve the task (i.e. they understand the most functional tool and the properties of the pipe cleaner) and have the ability to manufacture the target tool, then the question needs to be asked, ‘Why do children find tool innovation so difficult?’

Previous tool innovation literature offers several suggestions [13,15,16,18]. One is that children over-rely on social learning [13,15,16,18]. By 2 years, children have a well-established ability to learn by imitating others [18,21–23], to the extent that children (across cultures) copy causally irrelevant actions (over-imitate), for example wiping a stick across a box despite understanding the box can be opened by simply pushing the door [24–26]. As this social learning capacity results in the avoidance of children ‘reinventing the wheel’, it possibly prevents children from innovating, however it is doubtful that this is the full explanation for young children’s innovation difficulty [9,14–16].

Another explanation is that the difficulty occurs because tool innovation tasks are an example of an ill-structured problem, one requiring participants to generate the means (i.e. making a hook) of getting from a start state (i.e. the apparatus and objects) to the desired goal state (i.e. retrieving a basket) independently [13,14,16,17]. Solving an ill-structured problem like a tool innovation task makes demands upon participants’ executive function (i.e. retaining information, inhibiting incorrect strategies and switching between strategies), and as this control develops substantially during childhood, it has been suggested as a plausible limiting factor in children’s ability to solve such tasks [13,15–17,27].

Yet, situated cognition research suggests that learning is necessarily embedded in and mediated by surrounding practices [28–31]. Blitzer & Huebner [32] argue that unique aspects of human tool use arise not from cognitive capacities, but from complex relationships between humans and their environment. They cite evidence that, with environmental scaffolding, non-human primates use tools in more sophisticated ways. Similarly, while younger children seem to be less sensitive to the affordances—action possibilities—presented by novel potential tools, context and practice may change that sensitivity [33]. The context of experimental research is an unfamiliar and formal one with distinct linguistic patterns, physical layouts and procedures. The two studies presented here investigate potential impacts of the experimental context on children’s engagement in tool innovation tasks. Exploratory Study 1 looks broadly at the potential impact of conducting experiments in a context that primes exploration and innovation with tools, and Study 2, also taking place in a rich hands-on learning context, looks at the impact of ownership of experimental materials.

While there is a growing body of research investigating young children’s understanding of ownership, there have been no studies examining the role of ownership in children’s object selection and innovation in problem-solving tasks. At a basic level, an understanding of ownership emerges at around 2–3 years of age [34–37] and infants can infer ownership based on first possession when not provided with explicit ownership information [38,39]. At around the same age, children also show an understanding about ownership rights. For example, children protest if an owners’ rights are violated [40,41] and by the age of 3 children can infer ownership from control of permission (i.e. granting or denying permission) [42,43]. From around age 2, children show some understanding of ownership transfer. They understand that stealing does not transfer ownership [44]. However, it is not until around 4–5 years of age that children show an understanding that gift giving transfers ownership to the recipient [45].

Given young children’s understanding of object ownership and associated rights, young children’s failure to innovate may, in part, result from children correctly inferring that objects presented within a problem-solving task belong to the experimenter. Based on this inferred ownership, even when granted permission to use an object, children may feel obliged to use it in a manner that does not break with social norms governing object use, especially under circumstances in which the solution to the task involves physically altering the object in some way. In what follows, we present two studies that draw on prior studies on children’s tool innovation, but explore potential influences of environment and ownership.

2. Study 1: site and participants

This exploratory study took place in a dedicated making centre in a children’s museum in the USA. Artist educators greet families asking, ‘What would you like to make today?’ [46]. There is open access to tools such as soldering irons and glue guns, and materials such as fabric and wood. Children take home what they make, communicating a sense of ownership over materials. This site was purposefully selected because it targets the age group for the study and provides a visually rich context explicitly encouraging tinkering with tools and materials. Parents with children aged 3–8 years visiting the space were asked if we could invite their children to participate in the study. All participating parents granted written informed parental consent, and all participating children granted verbal assent, under the Institutional Review Board at George Mason University. Children (n = 57) ranged in age from 3 years, 3 months to 7 years, 8 months (table 1). Nearly all of the participating children were infrequent visitors to the museum. No items used in the experiment were present in other activities in the space.

(a) Material and procedure

Materials and procedure replicated Cutting et al.’s design [17], using the condition without any bending practice [17], but studying a wider age range of children. The study took place in the making centre in a screened-off experimental station that was not visible or audible to other visitors. Entering the station, the participants saw a vertical transparent tube with a bucket containing a sticker at the bottom and a small opening (diameter = approx. 5 cm) at the top. Next to the tube were a pipecleaner (length = 29 cm) and a piece of string (length = 29 cm). For Stage 1, children were told, ‘If you can get the bucket out of the tube, you can keep the sticker. These [indicating pipecleaner and string] are things that can help’. If the child did not retrieve the sticker after 1 min, including neutral verbal prompts like, ‘Can you think of how you might use these things to get the sticker?’ the experimenter began Stage 2: children were briefly shown a hook already made out of a pipecleaner and then allowed to continue trying with their own materials. If they still did not retrieve it after 1 more minute, in Stage 3 the experimenter said, ‘Watch this’ and took out her own
Table 1. Study 1’s children’s innovation of tools at different stages in the experiment at a making centre in a children’s museum in the USA (n = 57). For ‘age group’, age ranges are given, followed by the mean (m) age in ‘year, months’ format.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>N</th>
<th>Stage 1: before demonstration (%)</th>
<th>Stage 2: following target tool demonstration (%)</th>
<th>Stage 3: following tool creation demonstration (%)</th>
<th>Never succeeded (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–4 years</td>
<td>14</td>
<td>1 (7.14%)</td>
<td>4 (28.57%)</td>
<td>2 (14.29%)</td>
<td>7 (50%)</td>
</tr>
<tr>
<td>4–5 years</td>
<td>16</td>
<td>7 (43.75%)</td>
<td>8 (50%)</td>
<td>1 (6.25%)</td>
<td>—</td>
</tr>
<tr>
<td>5–6 years</td>
<td>11</td>
<td>4 (36.36%)</td>
<td>4 (36.36%)</td>
<td>2 (18.18%)</td>
<td>1 (9.09%)</td>
</tr>
<tr>
<td>6–7 years</td>
<td>16</td>
<td>13 (81.25%)</td>
<td>2 (12.5%)</td>
<td>1 (6.25%)</td>
<td>—</td>
</tr>
</tbody>
</table>

pipcleaner and made it into a hook. If, after 30 s, they did not retrieve the sticker, the children were coded, as in Cutting et al., as not succeeding, and the experimenter helped them to retrieve it [17]. The timing of prompts was strictly kept regardless of children’s actions. Cutting et al.’s design was selected because it minimized distractor items, thus more narrowly focusing on the tool innovation question, and it allowed for examination of the effects of different scaffolding prompts.

(b) Results

Overall, 49 of the 57 children were able to successfully devise a hook to retrieve the basket across all conditions (table 1). Of those, 25 were successful without prior demonstration within 1 min. Of the remaining 32, 18 were able to devise and use the hook after briefly seeing the bent target. Of the remaining 14, six were able to devise and use the hook after seeing the experimenter bend the pipcleaner. The remaining eight were informed verbally how to complete the task and were given the sticker.

Data from participating children were divided into the age categories used in Beck et al. since they most closely represented the range of ages of children in our study [15]. Resulting groups were 3–4 year olds (n = 14; range 3 years, 3 months to 4 years, 7 months; m = 4 years, 0 months); 4–5 year olds (n = 16, range 4 years, 10 months to 5 years, 9 months; m = 5 years, 3 months); 5–6 year olds (n = 11, range 5 years, 10 months to 6 years, 6 months, 2 months); and 6–7 year olds (n = 16, range 6 years, 11 months to 7 years, 8 months; m = 7 years, 3 months). The range and mean ages of our groups are fairly consistent with Beck et al. [15]. There were more participating females (62%) than males, but like prior studies, we found no performance differences associated with sex.

To detect differences between the age groups in terms of success without demonstration (Stage 1), we conducted Fisher’s exact tests (FET). Only one child (7.14%) in the 3- to 4-year-old group succeeded without any demonstration (and this was achieved by dragging the basket up the side of the bottle with a pipcleaner that became bent in the process rather than creating a hook in advance). However, 43.75% of 4- to 5-year-old group successfully devised a hook tool without demonstration within 1 min. This is significantly higher than the 3- to 4-year-old group (FET, p = 0.0039). There was no difference between the 4- to 5-year-old group and the 5- to 6-year-old group (FET, p = 1). Finally, the 6- to 7-year-old group performed significantly better than the 5- to 6-year-old group (FET, p = 0.04), and each of the younger groups.

If we consider success rates to also include those who devise a tool after being briefly shown a bent pipcleaner (Stage 2), we find that 35.71% of the 3- to 4-year-old group; 93.75% of the 4- to 5-year-old group; 72.73% of the 5- to 6-year-old group; and 93.75% of the 6- to 7-year-old group are now successful. Again, the 4–5-year-old is significantly more likely to be successful than the 3- to 4-year-old group (FET, p = 0.001). There were no significant differences among the older groups in success rates by Stage 2. Fifty per cent of the 3- to 4-year-old group were never successful on the task, whereas all of the 4–5 year olds were (FET, p = 0.002). There were no significant differences between the other age groups.

(c) Discussion

Study 1’s youngest (3–4 years) group’s performance is consistent with prior findings: these children are rarely successful on this tool innovation task without support and remain significantly less successful than older children, even with support. However, the next youngest group (4–5 years) in this study performs significantly better than the younger children, both without and with support. None of the prior studies on children’s tool innovations detected significant differences in success rates at this age. Likewise, we found a second significant difference between the 6- to 7-year-old group and all the younger ages, which is earlier than in prior studies.

Given our low sample sizes, caution is warranted in comparing our findings to prior studies, but the differences are suggestive. For instance, if we look at Beck et al., where the age groupings parallel those in this study, there were no differences between their 3- to 4-year-old group and their 4- to 5-year-old group [15]. Looking descriptively, only approximately 7% of their 4–5 year group were successful on the tool demonstration task, whereas approximately 44% of the 4–5 year olds in this study were (figure 1). Their task was identical to ours except that it included two additional matchsticks as distractor items, which may explain in part Beck et al.’s lower success rates. However, if we look at the Cutting et al. data, which had identical materials and procedure to ours, we find a similar pattern (figure 1) [17]. Restricting and regrouping our data to match the age ranges in the Cutting et al. condition we replicated (table 2), we find again that our younger groups are highly consistent with Cutting et al. at Stage 1. However, at Stage 2, 55% of the
Table 2. Study 1 findings compared to findings on the same task in Cutting et al. [17]. Study 1 age groups are reorganized and restricted in range to match Cutting et al. Age ranges are given in the ‘year, months’ format, with mean age (m) to the right of that.

<table>
<thead>
<tr>
<th>study</th>
<th>age range</th>
<th>n</th>
<th>Stage 1: before demonstration</th>
<th>Stage 2: following target tool demonstration</th>
<th>Stage 3: following tool creation demonstration</th>
<th>never succeeded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td>4.1–5.1 (m = 4.7)</td>
<td>26</td>
<td>2 (7.7%)</td>
<td>6 (23.1%)</td>
<td>10 (38.5%)</td>
<td>8 (30.8%)</td>
</tr>
<tr>
<td>Study 1</td>
<td>4.2–5.0 (m = 4.7)</td>
<td>12</td>
<td>1 (8.3%)</td>
<td>6 (50%)</td>
<td>1 (8.3%)</td>
<td>4 (33.3%)</td>
</tr>
<tr>
<td>Cutting</td>
<td>5.2–6.2 (m = 5.7)</td>
<td>28</td>
<td>4 (14.3%)</td>
<td>9 (32.1%)</td>
<td>7 (25%)</td>
<td>8 (28.6%)</td>
</tr>
<tr>
<td>Study 1</td>
<td>5.2–6.2 (m = 5.7)</td>
<td>18</td>
<td>9 (50%)</td>
<td>6 (33.3%)</td>
<td>3 (16.7%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

Figure 1. Comparison of percentages of children who successfully innovated a tool without demonstration (Stage 1) across Study 1, Beck et al. [16], and Cutting et al. [17]. Age ranges are given in ‘years, months’ format, followed below by the mean age (m) of the sample, and then the sample size.

4–5 children in our study were successful, whereas the rate for that age in Cutting et al. was 25%. Their older group had a Stage 1 success rate of approximately 14%, which was not significantly different from their younger group. However, in our data, children in that age range had a success rate of 50% (table 2) and were significantly better than the younger group, FET, p = 0.024.

To be sure, comparing descriptive success rates across diverse studies can be misleading, particularly given our relatively low sample sizes within age groups where a few successful children can, by chance, inflate percentage success rates. Nevertheless, while our findings for the youngest children are comparable to prior studies, we consistently find higher percentage success rates across slightly older children. Moreover, our exploratory study, even with its small sample sizes, seems to be more sensitive in finding significant differences in performance at earlier ages than prior studies. Some of these findings may be owing to variables that need to be more carefully controlled in future studies: for example, the population of children in families who elect to visit children’s museums likely differs from those in schools. However, while this may inflate overall success rates, it would not likely explain why our findings with the youngest children were nearly identical to prior studies, and why we found age differences not seen earlier. We consider two possible sources for the improved success rate: (i) the children’s museum’s making centre environment primes children to think of tool manipulation and innovation more readily; (ii) the environment, with its free access to use and take materials, reduces the inhibition children may have to bend or otherwise alter materials belonging to the experimenter.

Spontaneous comments from children in Study 1 provide anecdotal support that issues around rules and ownership of materials may impact performance: One 6 year old asked: ‘Am I allowed to switch tools? Am I allowed to use two?’ and then when shown a bent pipe cleaner, said ‘Oh, so you’re allowed to do that? Thanks! Got it!’ and quickly made the hook. Another 6 year old asked, ‘Can I like bend it?’ The emergence of these questions, about what is allowed in the experiment, even in a context where adults give children free access over tools and materials, prompts further exploration. Thus, Study 2 explored the role of object ownership in a similar problem-solving task for children in the 5- to 7-year-old range, as higher rates of innovation were seen in this age group in Study 1. The purpose of this experiment was to determine if providing children with explicit ownership information would affect children’s object selection and likelihood of children bending the pipe cleaner to form a hook.

3. Study 2: ownership site and participants

This exploratory study took place in a dedicated making space in a Science Centre in the UK. Written informed consent was collected from parents whose children, aged 5–7 years, were intending on visiting the Science Centre as part of an organized school trip. On the day of data collection, participating children’s verbal assent was collected prior to test in accordance with Northumbria University’s Ethics Board. Children (n = 69) ranged in age from 5 years, 2 months to 7 years, 11 months.

Children were randomly allocated to one of three conditions (experimenter owned, child owned or control condition) according to age group (table 3).
Table 3. Frequencies (and percentages) of children initially selecting either an owned or not owned object, in both the experimenter owner and child owner conditions (n = 46).

<table>
<thead>
<tr>
<th>condition/age group</th>
<th>object selected</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>experimenter owner (n = 23)</td>
<td>owned</td>
<td>4 (17%)</td>
<td>19 (83%)</td>
</tr>
<tr>
<td>6–7 year olds (n = 11) (m = 6.7; range = 6.4–7.3)</td>
<td>2 (9.5%)</td>
<td>9 (43%)</td>
<td></td>
</tr>
<tr>
<td>5–6 year olds (n = 12) (m = 5.4; range 5.2–6.2)</td>
<td>2 (8%)</td>
<td>10 (40%)</td>
<td></td>
</tr>
<tr>
<td>child owner (n = 23)</td>
<td>19 (83%)</td>
<td>4 (17%)</td>
<td></td>
</tr>
<tr>
<td>6–7 year olds (n = 11) (m = 6.6; range = 6.4–7.11)</td>
<td>8 (38%)</td>
<td>2 (9.5%)</td>
<td></td>
</tr>
<tr>
<td>5–6 year olds (m = 5.6; range = 5.2–6.3)</td>
<td>11 (44%)</td>
<td>2 (9.5%)</td>
<td></td>
</tr>
<tr>
<td>control condition (n = 23) 6–7 year olds (n = 13) (m = 6.5; range = 6.4–7.10)</td>
<td>7 (54%)</td>
<td>6 (46%)</td>
<td></td>
</tr>
<tr>
<td>5–6 year olds (n = 10) (m = 5.3; range = 5.4–6.3)</td>
<td>5 (50%)</td>
<td>5 (50%)</td>
<td></td>
</tr>
<tr>
<td>pipecleaner selected</td>
<td>red</td>
<td>blue</td>
<td></td>
</tr>
<tr>
<td>owned</td>
<td>not owned</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Materials and procedure

Children were shown a similar task to that used in Study 1 except that ownership of the target objects was manipulated. In addition, a wooden stick was added to ensure there was an equal number of materials that could be used to solve the task (pipe cleaners) and objects that could not be used to solve the task (distractor objects). The time children were given to solve the task was also increased to 1.5 min as pilot work found that older children were still attempting to solve the task after 1 min had elapsed. In Stage 1, half of the children in the Child Owned Condition (CO) were asked to choose a blue pipe cleaner and half a red pipe cleaner on the morning of testing. They were explicitly told that the pipe cleaner belonged to them and they would be able to take it home at the end of the day. The experimenter then told the child that she would keep the pipe cleaner in a safe place until the end of the child’s visit to the Science Centre and placed the pipe cleaner in an envelope marked with the child’s name. Stage 2 took place later in the day in a screened-off space in the Science Centre. Children were tested individually and upon entering the testing space were seated at a table, facing the experimenter, on which was placed a vertical transparent tube with a bucket containing a sticker at the bottom and a tiny opening (diameter ≈ approx. 5 cm) at the top. The experimenter individually placed four objects, a wooden stick, a red pipe cleaner, a blue pipe cleaner and a piece of string on the table in front of the child. Across conditions, the objects were always placed on the table in the same order and from left to right and each object was retrieved by the experimenter from an individual envelope. In the Experimenter Owned Condition (EO), as one of the pipe cleaners was being placed on the table, half of the children were told that the experimenter owned the blue pipe cleaner (i.e. ‘See this pipe cleaner? This belongs to me!’) and half were told that the experimenter owned the red pipe cleaner. No ownership information about the remaining pipe cleaner or distractor objects was provided. In the CO condition, the experimenter showed the child their name on the envelope and as the experimenter placed the child’s pipe cleaner on the table said, ‘See this pipe cleaner? This belongs to you’. As in the EO condition, no ownership information was provided about the other pipe cleaner or the distractor objects. However, across both of these conditions, attention was drawn to the non-owned pipe cleaner by asking children to name its colour. Prior to presenting the problem-solving task, children under the EO and CO conditions, while the experimenter was pointing at the ‘owned’ pipe cleaner, were asked ‘Who does this belong to?’ to ensure that the children had processed the correct ownership information. If they failed the control question, children were recycled through the procedure a second time. All children correctly answered the control question on either their first or second attempt. Children were then told, ‘If you can get the bucket out of the tube, you can keep the sticker. These [indicating pipe cleaners, stick and string] are things that can help’. Once testing commenced children received no feedback, only neutral prompts (e.g. ‘can you think of what you could use to help you get the sticker?’). Children in the Control Condition (CTC) were presented with the same materials and task but provided no ownership information.

(b) Results and discussion

In the EO and CO Conditions, children were given a score of 1 for first selection of the ‘owned’ pipe cleaner and 0 for selection of the ‘unowned’ pipe cleaner. For the CT Condition, children were given a score of 1 for first selection of the blue pipe cleaner and a score of 0 for selection of the red pipe cleaner. Children who made a hook were given a score of 1, and failure to have made a hook resulted in a score of 0. There were slightly more participating males (57%) than females, but like prior studies, we found no performance differences associated with sex. We used χ²-tests to analyse data where the sample size was sufficiently large, and FET when the sample size was deemed too small to permit use of χ²-tests. Given the number of tests the level of significance was adjusted to p = 0.0125 to keep the familywise error rate at 0.05.
In looking at the first object selected under the control condition, analysis showed no significant effect of whether children first selected the blue pipecleaner or the red pipecleaner (FET, $p = 0.10$). Thus, children showed no colour preference in terms of pipecleaner selection. However, analysis showed that explicit ownership information had a significant effect upon children’s initial object selection, $\chi^2(1, n = 46) = 19.57, p < 0.001$, with children in the CO condition significantly more likely (83%) to select the owned pipe cleaner than children in the EO condition (17%). Moreover, a similar pattern of results was shown across both 5–6 year olds (FET, $p = 0.001$) and 6–7 year olds (FET, $p = 0.009$) (table 3). The number of children seeking permission, either by directly asking the experimenter ‘Can I bend this?’ or ‘Can I use this?’ was also recorded. Results showed that in the EO condition more 6–7 year olds sought permission from the experimenter than in the CO condition (FET, $p = 0.005$). This difference fell short of significance for 5–6 year olds (FET, $p = 0.97$).

Turning to the number of children who successfully solved the task, analysis showed no significant effect of ownership condition for 5–6 year olds (FET, $p = 0.415$) or for 6–7 year olds (FET, $p = 1.0$). As there was no main effect of ownership condition, data were collapsed across experimental conditions to examine age-related differences. Analysis showed a significant effect of the children’s age group upon task success, $\chi^2(1, n = 69) = 6.52, p = 0.01$, with 6–7 year olds (60%) more likely to succeed than 5–6 year olds (29%).

This study demonstrated that ownership significantly affects first object selection, with children in the CO condition significantly more likely to select the owned pipe cleaner over the unowned pipecleaner than children in the EO condition. However, there was no evidence that ownership affects the likelihood of children’s ability to innovate a hook. Like prior studies (e.g. [13,15]), the current experiment found that 6- to 7-year-old children were more likely to bend a pipecleaner to form a hook compared to 5–6 year olds.

This study did however find that while the percentage of 5–6 year olds passing the task (29%) is comparable to Beck et al., 6–7 year olds appeared to have more success in passing the task in this study (60%) compared with 6–7 year olds (40%) in Beck et al. [15]. However, as discussed in Study 1, the relatively low sample size and making comparisons across studies using different materials mean that caution is required in interpreting these results.

4. Conclusion

The hook innovation task discussed in these studies is a challenging ill-structured problem for young children. Cutting et al.’s targeted experiments focused on dimensions such as minimizing distractor items compared to prior studies, and demonstrating examples to prime memory, yet generally found that for children under 6, even with scaffolds, tool innovation remained elusive [17]. Yet, all tasks shared features of the experimental setting including unfamiliar adults enacting scripted, timed activities, a consenting procedure and novel materials. Contextual information is particularly important in ill-structured problems [47] and the experimental context does not seem primed for children to bring to mind innovative solutions.

These two studies investigated different aspects of the context of the experimental situation in which prior children’s tool innovation studies took place. Study 1, an exploratory study, found that when the experiment took place in a making centre that gives children permission to explore and tinker with materials, children in the 3- to 4-year-old age group performed similarly to prior studies, but older groups performed notably better. In addition, Study 1 found significant differences in performance at earlier ages from prior studies, with key gains in the 4–5 year old group and again at 6–7 years.

This pattern of findings may lend support to the view that performance on the hook tool innovation task is limited by demands on executive function. Study 1 lessens these demands by limiting distractor items and by setting the children up in a context that is likely to prime innovation and reduce the potential limiting effects of the experimental setting. Study 1’s findings show gains in success rates in the 4–7 year olds that differ from prior studies on tool innovation, but parallel other findings on executive function development. The hook tool innovation task requires children to inhibit their likely first response to use the items without altering and places demands on cognitive flexibility to picture the pipecleaner in different forms; these are both executive functions that have been found to be quite limited in 3 year olds but show gains from 4–7 years [48,49]. Future research should establish the robustness of Study 1’s findings with larger samples and explore the tool innovation task’s connection to executive function, for instance by correlating children’s success rates on the tool innovation task with standard assessments of executive function, and systematically varying task dimensions to assess the relative demands on inhibition and cognitive flexibility.

Study 2 more carefully examined the dimension of object ownership and found that children were significantly more likely to select an object they were told they owned over those owned by the experimenter. However, there was no significant effect of ownership condition on tool innovation. It may be that the success rates were already inflated by the affordances of the rich setting and thus masked any effect of ownership, so future research should disentangle these components more carefully.

These studies have limitations. Both have relatively small samples drawn from visitors to museums/science centres who may systematically differ in ways that matter for interpreting findings. Study 1 lacks a control group. There may be cross-cultural differences between the current and prior studies. Further studies are necessary to see whether the findings hold with larger samples and to more carefully examine the contextual aspects of environment and ownership on innovation.

**Ethics.** These studies were approved by the George Mason University and Northumbria University institutional ethics boards.

**Data accessibility.** Supporting data for this article can be accessed by contacting the corresponding author(s).

**Authors’ contributions.** Study 1 was designed and carried out by K.M.S. and A.W.K. Study 2 was designed and carried out by M.A.D. and S.K. All authors participated in drafting, revision and final approval.

**Competing interests.** We have no competing interests.

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