SUPPORTING CHILDREN'S TOOL INNOVATION.

by

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Abstract

The existing research has demonstrated young children's difficulty with solving novel tool innovation problems. Through nine experiments this thesis investigates children's tool innovation, focusing on whether this can be supported and the conditions under which children are more likely to succeed. In Experiments 1-3 the effect of prior experience with premade tools on innovation is explored. In Experiment 4, I explored whether directing an adult to solve the Hooks task made young children more likely to innovate a tool solution. In Experiment 5, I aimed to discover whether children's tool innovation can be predicted by their divergent thinking ability. In Experiments 5-8 I studied how priming spatial distance, and in turn abstract thinking, affects subsequent tool innovation. In Experiment 9 I began to explore whether priming children to engage in analogical problem-solving can facilitate subsequent tool innovation. Overall, this thesis has suggested that our current understanding of children's tool innovation may underestimate their potential. In the concluding chapter of this thesis, I summarise the key findings of this thesis, limitations and suggestions for future research.

Ethics

The research carried out for this PhD thesis was covered under reference ERN_09-048 from the UoB STEM Ethics committee.

When research was carried out in school, consent was always given by the headteacher in the first instance. A letter was always sent to parents/guardians of children eligible to take part in the research. This included detail of the proposed studies as well as contact details for myself and my lead supervisor, Sarah Beck, should parents/guardians wish to ask any additional information. Included with the letter was an opt-out consent form. When research was carried out in a museum, consent was given by parents/guardians who signed a consent form on the day of testing.

All data was stored without personal information. No names were recorded during data collection and thus data was anonymised. Further, I only recorded month and year of birth. On the one occasion that video data was obtained, the raw data was stored securely on University computers.

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Key Term	**Definition**
Tool Innovation	The modification of materials to make a novel tool to solve a physical problem. These ‘innovations’ are not the result of social learning and therefore are an *independent invention* (Carr et al, 2016).
Tool Manufacture	The physical act of making a tool. This may be done via social learning e.g. a tool-manufacture demonstration or may be done independently via asocial learning.
Divergent Thinking	A thinking process which involves generating multiple ideas and solutions.
Creativity	The use of original ideas to create something which is novel and useful and/or satisfying.
Analogical Reasoning	The cognitive process of making comparisons, by drawing on our knowledge and experiences. We employ analogical reasoning when we make decisions, judgements and solve problems.
Abstract Thinking	The ability to think about objects and ideas that are not physically present. Closely related to symbolic thinking and involves thinking beyond ‘concrete’ ideas.
Spatial Distance Priming	A methodological procedure that creates psychological distance by encouraging participants to think about places that are spatially distant from themselves. E.g. showing a series of pictures of increasing spatial distance from the participant (from their current location to outer space).

Chapter 1

Introduction

1.0 Overview

Children are immersed in a tool-rich culture, from simple tools such as spoons and cups to more complex tools like touchscreen tablets and mobile phones. It is no surprise that their knowledge of tools grows rapidly in childhood and they become proficient tool users from an early age. Despite this, the existing literature on children's tool innovation suggests a disparity between their tool using capacity and their ability to invent novel tools for themselves. Our current understanding of children's tool innovation is a pessimistic one. This thesis presents a series of experiments which explored the conditions under which children's tool innovation can be facilitated, to ascertain whether young children's capacity for tool innovation might be better than we think.

In this introductory chapter I will briefly discuss the literature on children's tool use. I will then review evidence from the non-human animal and developmental literature on the respective abilities of animals and children in the domains of tool innovation and physical problem-solving. I will review in more detail the literature that has focused on one particular measure of children's tool innovation, the Hooks task. I will progress to discuss what might make tool innovation, as measured by the Hooks task, difficult for children and the available evidence from the literature to date. I will discuss the approach to studying children's tool innovation that this thesis will take, focusing on whether it is something which we might be able to support. Finally, I will outline the experiments which will be presented in this thesis.

1.1 Children's Tool Use

One of the first tools that infants are introduced to and learn to use, is the spoon. Connolly & Dalgleish (1989) conducted a longitudinal study of spoon use in children aged 10-58 months, to see how this skill develops. Children's actions with the spoon are crude to begin with, they bang it on the table, put it in their mouth repeatedly and hit their dish with it. These repetitive actions provide children the opportunity to learn about the physical and mechanical properties of the spoon. Their behaviour becomes more goal-directed once their intention is to move food from the dish to the mouth with the spoon. A sequence of actions appears and becomes increasingly efficient with the emergence of a stronger dominant hand preference, visual monitoring and the use of a single grip pattern.

Self-directed actions involving tools, such as self-feeding with a spoon, are likely to be easier for children compared with using tools to act on another object (Keen, 2011; McCarty, Clifton & Collard, 2001). However, infants as young as 8 months can use a tool to obtain an out of reach object, when there is no spatial gap between the tool and the target (van Leeuwen, Smitsman & van Leeuwen, 1994). From 8 months children demonstrated that they could use a hook tool to bring a toy within reach, when the toy was rested against and on the inside of the tool. As the spatial gap increased, by varying the position and orientation of the tool and toy, children's success at this age diminished. From 18 months, children begin to use a rake tool to bring a desired object within reach, in the presence of a spatial gap between the target object and the tool (Rat-Fischer, O'Regan & Fagard, 2012). Between the age of 18 and 26 months, children cope with larger spatial gaps between the toy and tool and are increasingly successful. This demonstrates that children's development of tool use is a continual and gradual process, rather than an ability which emerges suddenly (Lockman, 2000).

1.1.2 Children's Tool Knowledge

Everyday observations of infants and young children demonstrate their remarkable understanding of tools, their intended functions and how to use them. In experimental studies, Casler & Kelemen (2005) demonstrated how children as young as 2 years learn quickly about the function of objects. 2- to 4- year olds were familiarised with two novel objects, a 'blicket' and a 'dax'. One object was demonstrated turning on a special light, whereas the other tool was not demonstrated performing any function but was paid equal attention. Both objects were equally capable of being used to turn on the light. On test trials, children at all ages chose the demonstrated tool to turn on the light in the box and avoided using that tool when asked to perform a different action (crushing crackers). One exposure to an adult using a novel tool for a purpose was enough to become an enduring representation of what that object is ‘for’. Similarly, Casler, Terziyan and Greene (2009) demonstrated that 2- and 3-year-olds display a strong awareness of the right and wrong ways in which tools should be used. They did so by protesting when both familiar and novel objects were used in a way different to that which had been demonstrated, for example when a crayon demonstrated to be used for colouring was subsequently used to comb a doll’s hair.

Indeed, by age 6, children’s knowledge of what a tool is ‘for’ can be a hindrance to their ability to solve problems, when they are required to use a tool flexibly in a nonnormative manner. Defeyter and German (2003) found that 6- and 7-year-old children were less likely than 5-year-olds to choose the only tool suitable for pushing out a toy from a tube first, when its function had previously been demonstrated by the experimenter (a pencil for writing, or a straw for drinking). The older children also were slower to use the target tool to attempt the problem than younger children. These findings extended to novel objects, when the function of a novel target tool was demonstrated, older children were slower to select that tool first to solve a problem that required the use of that tool in an alternative way. These findings are a demonstration of ‘functional fixedness’ which has been consistently shown to appear around the age of 6 years (Defeyter & German, 2003; German & Defeyter, 2000). Children younger than this appear to be more immune to functional fixedness and can view a demonstrated function of an object as just one possible way to use it, from a range of other possibilities. For older children, a demonstration or pre-existing knowledge of an object’s function hinders their ability to use that object flexibly in order to achieve a goal.

Children learn about the function of objects and use this knowledge to guide their future problem solving from an early age. This allows children to interact with their environment and solve problems efficiently, when they need to select and use tools for their typical function. By age 6, this can be a double-edged sword for children, when functional fixedness emerges as a cost of an otherwise helpful way of organising their knowledge of object function.

In summary, children's ability to learn about tools, their functions and how to use them emerges early and progresses rapidly across childhood. To date, research has been focused on children's tool using behaviours. By comparison, much less is known about the ways in which children's ability to make tools develops. In the next section, I will review some of the evidence of tool making and innovation in non-human animals, before progressing to discuss the literature on children's tool making and innovation.

1.2 Non-Human Animal Tool Making and Innovation

Non-human animals have been well documented using tools both in the wild and in captivity. Much animal tool use is for the goal of retrieving food. One example is the nut-cracking behaviour of chimpanzees (Whitesides, 1985) and capuchins (Fragaszy, Izar, Visalberghi, Ottoni, Gomes de Oliveira, 2004), who crack nuts open using stone tools to hit them against an anvil. Chimpanzees use sticks to retrieve bone marrow after opening the end of the bone with their mouths (Boesch & Boesch, 1990). Non-human animals might also use tools for a protective function, such as when chimpanzees use long sticks to dip for fierce driver ants (McGrew, 1974). Tools might also be used to help non-human animals navigate their natural habitat. Breuer, Ndoundou-Hockemba and Fishlock (2005) observed a wild gorilla using a branch as a walking stick to help her to gage water depth as she crossed a pool in the Congo, and another female gorilla use a trunk as a bridge to help her to cross a deep patch of swamp. Non-human animal tool-use is common, at least in non-human primates, and they use tools for a variety of purposes.

As well as evidence that they use tools, there is a growing evidence base of tool making amongst some non-human animal species, although this is much rarer (Shumaker, Walkup & Beck, 2011). Orangutans (van Schaik et al., 2003), bonobos (Walraven, van Elsacker & Verheyen, 1993) and wild chimpanzees (Sousa, Birdo & Matsuzawa, 2009) make leaf-sponges, by compressing fresh leaves into a single mass that they then use as a sponge to retrieve water for drinking from inaccessible tree holes. Chimpanzees will modify a stick up to 5 times to make it suitable for cleaning kernels from panda shells (Boesch & Boesch, 1990). They make tools the correct length for purpose, by standing on twigs or branches and then pulling, cutting with their teeth or breaking them with their hands. They also reshape tools, making them sharper with their teeth or by removing leaves and bark.

Perhaps most striking, is the evidence of tool making in corvids both in the wild and in the laboratory. Observation of wild New Caledonian Crows describe their impressive ability to make tools. They shape panadus leaves with their bills to make tools (Hunt and Gray, 2003) and break and shape twigs to make hook tools (Hunt and Gray, 2004). Hunt and Gray (2004) observed crows in the wild, at a feeding station which they had set up by placing food into vertical holes that had been drilled in a dead log. Small, leafy branches were placed in the holes in the feeding log. Each leafy branch had several forked twigs on it that had the potential to be used to make a hook tool. On three occasions, an adult crow was observed making a hooked-twig tool from this leafy branch in order to retrieve food from the holes in the log. The crow's dependent offspring was also observed seven times making a hook tool from this material. To make the hooked-twig, the crows first selected a fork made from two twigs. They then broke off one twig at the branch junction and discarded it. Next, they broke off the other twig just below the junction, which became the tool twig. They sculpted the hooked end of the twig tool with their bill and removed any leaves, to be left with the tool they went on to use to extract food from the holes in the feeding log.

Tool making has also been closely observed with captive New Caledonian Crows (Weir, Chappell & Kacelnik, 2002). Researchers were observing whether the crows could choose the appropriate tool to solve a task which required a hook tool to retrieve a food-baited bucket from a transparent plastic tube. Crows were given a straight and hooked piece of pliable wire. When one crow flew off with the hooked tool, another crow, Betty, bent the straight piece of wire to make her own hook. The experimenters subsequently gave Betty only straight pieces of wire to solve task and, on the majority of trials, she continued to produce hooks using a number of different methods. For example, the authors describe how she wedged the wire on some sticky tape at the bottom of the test tube, then pulled at the other end of the wire with her beak in order to bend it. On another occasion, she held the wire with her feet whilst pulling the other end with beak to fashion a hook.

The crows had not been shown how to make hook tools previously and their only experience with a pliant material had been 1 hour of free manipulation with pipecleaners, one year before the experiment took place. The crows were familiar with the test apparatus but not with the wire material. They had experience of solving the task with a premade hook tool, but not of how to manufacture a hook tool of their own. Betty was not required to spontaneously innovate the solution to the task (that she needed a hook to retrieve the baited bucket) but she did need to come up with the means to make the solution for herself, when only presented with a straight piece of wire.

More recent findings suggest that Betty’s behaviour in this experiment might not represent an innovative solution to a novel problem. Comparing Betty’s hook manufacture with the hook tool manufacture of wild species, Klump, Sugasawa, St Clair and Rutz (2015) note that the methods used are remarkably similar. Since Betty was caught from the wild as a young bird, it is suggested that she may have been expressing behaviour which was part of her natural repertoire, although some causal understanding of the task and innovative problem solving cannot be ruled out.

Compelling evidence of innovation of this kind comes from another corvid species, the rooks (Bird & Emery, 2009). All four captive rooks studied spontaneously made a hook from a straight piece of garden wire to solve the task used by Weir and colleagues (2002) with the New Caledonian Crows. They did this despite no prior demonstration of hook manufacture, or experience with garden wire. However, as was the case with Betty, they had experience with the test apparatus and with using premade hooks, albeit made from other materials such as dowel.

Other striking examples of spontaneous tool innovation have been reported in captive cockatoos, a species who are not known to use tools in the wild (Auersperg, Szabo, von Bayern & Kacelnik, 2012; Laumer, Bugnyar, Reber & Auersperg, 2017). 'Figaro' the cockatoo spontaneously made stick tools, by breaking off splinters from a large wooden beam inside his enclosure, in order to rake closer a cashew nut behind a wire mesh (Auersperg et al, 2012). Laumer and colleagues (2017) also found that cockatoos could bend wire to make a hook and unbend wire to make a straight tool, in order to retrieve a food reward from a transparent tube. They had prior experience of making straight stick tools, but no experience of using pliant materials such as the wire or of using hook tools.

Recent evidence of spontaneous tool innovation has also been reported in orangutans (Laumer, Call, Bugnyar, Auersperg, 2018). Two out of five orangutans spontaneously bent a piece of wire to make a hook, in order to retrieve a handled bucket from a tube. One of the successful orangutans had previous experience of using a rigid, premade hook in another context, whilst the other had no experience of using hook tools at all. By comparison, a task requiring unbending a piece of wire to make a long, straight tool was easier and four out of five orangutans showed successful innovation.

The studies of corvids' tool making, and more recent evidence of spontaneous tool innovation in cockatoos and orangutans, provide an insight into the impressive ability of some non-human animals to make hook tools to solve physical problems. These findings have also sparked the interest of developmentalists. In the next section I will discuss the literature looking at children's tool making and spontaneous tool innovation.

1.3 Human Tool Making and Innovation

Learning to use tools is a critical part of human development and our capacity to do so is what makes us experts at using tools to solve problems. Moreover, our robust knowledge of tools and their functions allows us to go on to innovate specialist, novel tools to solve problems (Tomasello, 1999). Tool use has been widely used as way to measure children's approach to problem solving (Keen, 2011), since observing their manual actions can provide insight into the ways in which children plan and execute a sequence of actions to achieve a goal. More recently, the studies of tool making in corvids and their surprising abilities have renewed researchers' interest into the ontogeny of children's tool-making ability. Although children are competent tool users, not all aspects of tool cognition are as simple as others. In particular, innovation of tools to solve novel problems is especially difficult for young children.

Children display innovation in many different ways: through their exploratory play, creative drawings and imaginary games to name a few. However, this thesis will focus on one particular aspect of children's innovation, specifically their innovative behaviour in the context of creating tools to solve novel physical problems. Definitions of tool innovation often lack operationalisation of what exactly is meant by the term ‘innovation’, which can make discussions of this important aspect of human behaviour less clear. Carr, Kendall & Flynn (2016, p. 1515) offer a definition of innovation, within the physical domain as “…a new, useful, and potentially transmitted learned behaviour, arising from asocial learning (innovation by independent invention) or a combination of asocial and social learning (innovation by modification), that is produced so as to successfully solve a novel problem or an existing problem in a novel manner.” When I refer to children’s tool innovation throughout this thesis, I refer to their independent invention: an innovation which has emerged that is not a direct result of social learning.

Beck, Apperly, Chappell, Guthrie and Cutting (2011) were the first to adapt the task designed to study tool innovation in captive New Caledonian Crows for use with children. For clarity, throughout this thesis, this task will be referred to as the **Hooks task**. In their study, children were required to retrieve a bucket containing a sticker from a transparent vertical cylinder. Children could not fit their hands inside the cylinder to retrieve the bucket and therefore were required to use a tool, which they needed to make for themselves from the materials provided. Beck and colleagues (2011) made a distinction between two types of tool making: tool innovation and tool manufacture. Tool manufacture was defined as being able to physically transform the materials into a tool, having been shown how to do so by an adult experimenter. Tool innovation required children to not only be able to manufacture a tool, but also to bring to mind the type of tool that they needed for themselves. Innovation requires innovation of the solution and the means to solve the task, whilst tool manufacture requires copying and not innovation. By Carr and colleagues’ (2016) definition, tool innovation on the Hooks task is equivalent to innovation by independent invention, since it comes about as a result of asocial learning rather than as a direct result of any social instruction.

First, Beck and colleagues (2011) investigated whether children could choose the correct tool that they needed to solve the task. Children had the choice of a straight pipecleaner or a pipecleaner bent at one end to form a hook. From 4 years of age, children were significantly more likely than chance to pick the hooked tool rather than a straight tool to solve the task. This showed that children could recognise the correct tool to solve the problem from a given array and had an understanding of how to use hook tools.

In the second experiment of this paper, Beck and colleagues (2011) investigated whether children could innovate a tool to solve the problem for themselves. Children were given a straight pipecleaner, a piece of string and two small sticks and were told that if they could get the sticker out of tube then they could keep it. Children were given no further instructions and were given a minute to attempt the task. The appropriate solution was to bend the pipecleaner at one end to make a hook that would retrieve the bucket from the cylinder. Performance was poor in children aged 4 years and improved between the ages of 5 and 11. It was not until around 8 years of age, that just over half of children successfully innovated a tool. A comparison group of adults ages 16-17 years were tested on the same task and all were successful at innovating a hook tool. By contrast with their innovation performance, children found manufacturing a hook tool, following an adult demonstration, remarkably easy.

In their third experiment, Beck and colleagues (2011) looked at whether children failed to innovate a tool due to poor communication of the task, or a misunderstanding of the task instructions. They wondered if children who failed to modify the materials to make a hook, did so because they thought they were not allowed to bend the pipecleaner and had to use the materials as they were originally presented to them. Children also might not have been aware of the functional properties of the pipecleaner (that it was pliable). They checked for these alternative explanations by giving half of the children the opportunity to manipulate the materials before attempting the Hooks task. Children were familiarised with the materials by watching the experimenter demonstrate how to transform the materials in various way and having the opportunity to copy them by manipulating the materials for themselves. The pipecleaner was wound around a pen and then pulled off to show children that the pipecleaner holds its shape once bent. The distractor items were also manipulated. The string was laid in an s-shape and the matchsticks were laid out to make a square shape. Beck and colleagues (2011) found innovation rates were low again on the Hooks task and the familiarisation phase did not improve children's performance. This suggested that children's difficulty was not likely to be explained by poor communication of permission to adapt the materials or a lack of knowledge about the pliable nature of the pipecleaner.

Since the original study by Beck et al (2011), children's difficulties with innovation by independent invention on the Hooks task and competence at manufacturing a tool following adult demonstration have been replicated a number of times (Cutting, Apperly & Beck, 2011; Cutting, Apperly, Chappell & Beck, 2014; Gonul, Takmaz, Hohenberger & Corballis, 2018; Nielsen, Tomaselli, Mushin & Whiten, 2014; Sheridan, Konopasky, Kirkwood & Defeyter, 2016). Young children's difficulty on tool innovation tasks has also been demonstrated on another task. Although Tennie and Tomasello (2009) were investigating cumulative culture and social learning in chimpanzees and children, their study also allowed children an opportunity to innovate a tool to solve a problem. They presented 4-year-olds with a tool problem that required them to bend a piece of wool wire into a loop, in order to pull a reward on a platform closer. No children spontaneously innovated the solution to the problem, which required independent innovation of a novel solution to a novel problem. However, the majority went on to make a loop following an adult demonstration. This is further evidence that whilst young children are capable of manufacturing tools from an early age, their ability to innovate tools of their own might emerge much later.

Cutting et al (2011) also investigated children's tool innovation on an unbending task. Children were presented with a transparent tube containing a pompom with a sticker on it. The sticker could not be retrieved without use of a tool to push the pompom out of the tube. Children were presented with a piece of string (distractor item) and a pipecleaner which had been bent in half. Children were required to unbend the pipecleaner in order to make a straight tool which was long enough to push out the pompom. Although more children were successful on this task compared with the hook bending task, levels of successful tool innovation remained low. Only one-third of 4- to 5- year-olds and around half of 6- to 7-year-olds were successful. The authors also noted that some of the children who succeeded on the task may have unbent the pipecleaner unintentionally, meaning that the true number of children who arrived at the solution via insightful tool innovation may have been lower.

In the absence of research documenting children's innovative tool making on other tasks, I will discuss another example of innovation which required children to use water as a tool, in order to solve a physical problem. Hanus, Mendes, Tennie and Call (2011) gave children aged 4, 6 and 8 years a task which required innovative problem solving. Children first used a jug filled with water to water some plants. This jug was then placed 50-80cm away from the test apparatus. The apparatus was a transparent, vertical tube containing a peanut. Children were told that if they could retrieve the peanut from the tube, they would win a reward (Kinder Egg Surprise). Children could not reach the peanut by putting their hand into the tube. The task solution required innovative problem solving. Although children were not required to manufacture a tool for themselves, children needed to recognise the jug filled with water as a tool and use it in a flexible way, to pour water into the tube and raise the level of the peanut until it could be retrieved from the tube. Four-year-old children rarely solved the problem for themselves. Performance increased with age and just over half of 8-year-olds were able to use the water as a tool to make the peanut float to the top of the tube.

Since the empirical work on this thesis was completed, Ebel, Hanus & Call (2019) have also studied children's tool innovation on the Floating Peanut Task with six-year-olds. They varied children's pre-test experience, in order to determine whether functional fixedness (caused by watering plants in the warm-up exercise) might explain low innovation rates. Children either did not water plants at all, did so once or did so five times. They found that children's rates of innovation were low. Their experience of watering plants did not affect their subsequent likelihood to innovate the solution to use water as a tool to retrieve a ball and therefore functional fixedness did not explain their difficulties with the task.

The pattern of children's success on the Floating Peanut Task is very similar to their performance on the Hooks task (Beck et al, 2011). Both are examples of innovative problem solving that appear to be difficult for young children. In the next section, I will discuss some of the research which has looked at why children might find tool innovation difficult.

1.4 Why Is the Hooks Task Difficult for Children?

The first series of studies looking at tool innovation on the Hooks task, conducted by Beck et al (2011), concluded that tool innovation is difficult for children, despite their proficiency as tool users. These experiments demonstrated that children could identify the tool needed to solve the task when it was premade, and that poor innovation was unlikely to be explained by a lack of understanding of the pliable nature of the tool material. They also demonstrated that children had the dexterity to make a tool when they were shown how to do so. Given that children are able to choose the correct tool and manufacture a suitable tool after demonstration, it is unlikely that their tool innovation difficulties lie in a lack of knowledge of tools or with the physical shaping of a tool.

1.4.1 Task Pragmatics

Since this original study, several follow up experiments have pursued the question of what makes tool innovation so difficult children, using the Hooks task paradigm. Cutting and colleagues (2011) explored the possibility that children's poor performance on the Hooks task could be due to difficulties with perseveration or task pragmatics. They found that children's performance on the Hooks task before demonstration was poor and that this extended to another tool innovation task which required children to unbend a pipecleaner to make a long tool, to push a pom-pom out of a horizontal tube. They found that children's poor performance could not be explained by a tendency to perseverate with an incorrect solution. Children rarely perseverated with an incorrect tool for the entire period of testing.

In a second experiment, Cutting and colleagues (2011) amended the task instructions to reduce the likelihood that children failed the Hooks task as a result of permission or pragmatics. Previous instructions advised children that the materials offered "may help" them to retrieve the sticker, which could have been interpreted by children that one of the materials in their given state would be sufficient to solve the task. This was changed so that children were explicitly told that they needed to make something with the materials in order to retrieve the sticker. Innovation rates remained low, and there were no significant differences between the experimental and control groups, suggesting that permission or pragmatics were also unable to explain children's failure to innovate tools.

1.4.2 Testing Environment and Sense of Ownership

Sheridan and colleagues (2016) have also explored children's performance on the Hooks task, examining the effect of environment and ownership on children's tool innovation. Children performed the task in a making centre within a children's museum, unlike previous studies which have taken place in a school setting (e.g. Beck et al, 2011;

Cutting et al, 2011). They replicated low rates of innovation in 3- to 4- year olds but found higher rates of innovation than expected in 4- to 7- year-olds. In the absence of a comparison group, it is not possible to conclude from this study whether or not environment might affect children's likelihood to innovate tools, although this does warrant further investigation. Fewer than half of children aged below 6 years solved the Hooks task, demonstrating that environment alone is unlikely to account for young children's difficulties with this task. They also found that children were no more likely to innovate a hook tool based on whether they were told that they or the experimenter owned the test materials. A sense of ownership over the materials did not have any effect on subsequent innovation, providing further support that their difficulties do not appear to lie in issues surrounding permission.

1.4.3 Cultural Influences

So far, the studies discussed have only been conducted with children from Western backgrounds. Nielsen and colleagues (2014) carried out a tool innovation study (Hooks task) with 3- to 5- year-olds from urbanised Western and remote South African indigenous communities. Children from the indigenous communities have less access to technology and manufactured toys which are commonplace in Western communities. Rather, they play with objects they find in their environment, such as sticks, stones and discarded tyres (Nielsen et al, 2014). Despite this, they found that children were equally poor at the version of the task that required them to innovate a hook tool of their own from a pipecleaner, without any demonstration. In line with the findings discussed so far, manufacturing a tool following an adult demonstration was relatively easy for children in both cultural groups. This demonstrates that children's difficulties with tool innovation appears consistent across at least two very different cultures.

1.4.4 Executive Functions

Executive functions refer to a group of mental processes which are required when we have to concentrate and pay attention. Generally, the core executive functions are considered to be inhibition (including inhibitory control, self-control, and selective attention), working memory, and cognitive flexibility (sometimes called set shifting or task switching) (Miyake et al, 2000; Diamond, 2003). These core executive functions are pre-requisites for higher order executive functions such as planning and problem solving. Given the complex nature of tool innovation behaviour, it is almost certain that it places demands on executive functions. Beck, Williams, Cutting, Apperly & Chappell (2016) investigated whether individual differences in executive functions, including inhibition, working memory and task-switching, could predict children's performance on the Hooks task. None of these measures of executive function were predictive of innovation, and thus are unlikely to explain children's tool innovation difficulties.

In another study looking at executive functions and tool innovation, Gonul and colleagues (2018) found that neither inhibitory control nor hierarchical structuring ability were predictors of tool innovators on the Hooks task. Even children who scored very highly on these measures were not likely to innovate a tool, suggesting that neither deficits with inhibiting prepotent responses or hierarchical structuring are at the root of poor tool innovation ability. That is not to say that the process of innovating a tool does not require children to engage in inhibitory or hierarchical structuring processes, rather that they alone are not sufficient to promote spontaneous innovation.

A further study explored the possibility that perseverance, a difficulty with task-switching, could explain poor Hooks task performance (Chappell, Cutting, Apperly & Beck, 2013). Half of the children were prompted to try something else every 10 seconds by the experimenter “What else could you do?” whilst the other half of the children attempted the task with no prompting or interruptions. This did not significantly improve (or hinder) tool innovation on the task. This provided further support that perseverating and pragmatics (permission) were unlikely candidates to explain children’s difficulty with innovating the solution to the Hooks task. Chappell et al (2013) found that children’s difficulties with the Hooks task were unlikely attributed to impulsivity. They gave children the opportunity to freely explore the test materials before being allowed to engage with the test apparatus. This not only gave children a chance to familiarise themselves with the properties of the materials, but also enforced a delay before children could attempt the task. The aim was to reduce the likelihood of impulsive actions. If impulsivity was causing children’s poor performance, children who had the chance to explore the materials and a delay before being allowed to act upon the apparatus ought to have been more likely to solve the task than children who did not have this experience. However, the delay and chance to explore the test materials did not make children more likely to innovate a tool to solve the task and therefore impulsivity or failure to explore the materials cannot explain children’s difficulties on this task.

In conclusion, although the Hooks task undoubtedly places demands on executive functions, attempts to identify a single measure of executive function which predicts have not been fruitful. Individual differences in executive function ability seems unlikely to account for the differences we observe in children’s tool innovation on the Hooks task. In pursuit of the question of what makes an innovator, we might turn to alternative personal characteristics as potential explanations. In Chapter 4 of this thesis, I investigate whether children’s Hooks task success can be predicted by their divergent thinking ability.

1.4.5 Affordance Visibility of Tool-making Materials

Neldner, Mushin and Nielsen (2017) outlined that the two key missing pieces of information that children have to bring to mind to solve the Hooks task are: the ideal shape of the tool needed (a hook) and how to construct that shape from the given materials (bend the pipecleaner). They proposed that one reason children might fail to generate the tool solution is that they lack the appropriate understanding of the physical affordances of the material. In their study, they aimed to make the affordances of the tool making material visible, without removing the requirement for tool innovation. Three- to five- year-old children from Western and rural, Indigenous communities were presented with the same Hooks task apparatus used in previous studies (e.g. Beck et al, 2011). In the opaque affordance condition, children were given a straight pipecleaner to attempt the task which they needed to bend in order to make a hook to retrieve the bucket. In the visible affordance condition, of children were given a pipecleaner which had a hook at one end and was curled over at the other, non-hook end, making the tool too short to retrieve the bucket from the tube. Children were required to uncurl the non-hook end of the tool, to make it long and straight enough to retrieve the bucket. Thus, children were required to innovate a tool in both conditions, but the affordances of the tool-making material were made visible in only one of them.

Neldner and colleagues (2017) found that across cultures children were significantly more likely to innovate the ideal tool in the affordance visible condition, when the pipecleaner had been bent at one end and curled at the other. Although innovation was better in the visible affordances condition, it was still difficult for the majority of children and less than half made an ideal tool. This suggests that although making the affordance of the tool-making material helped some children to solve the Hooks task, this alone cannot account for children’s difficulties with tool innovation.

1.4.6 Ill-Structured Problem Solving

One position which has been upheld is that the ill-structured nature of tool-innovation tasks such as the Hooks task is what makes them difficult for children. This has been proposed by Cutting and colleagues (2011). Ill-structured problems, unlike well-structured problems, lack information about either the start or goal states or the steps required to transform from one state to another (Reitman, 1965). The participant is required to produce their own information about how to fill these gaps. In the case of the Hooks task, children are provided with information about the start and goal states of the problem. At the start, the test apparatus and materials are laid out in front of them and the goal of the problem, to retrieve the bucket from the tube, is explained by the experimenter. However, children are not told how to transfer from the start to the goal state i.e. that they need to make a hook with the pipecleaner and use it to retrieve the bucket. Given this, it is most likely that children's difficulty solving the Hooks task is in bringing to mind the solution required to reach the goal state.

Support for this explanation can be taken from the finding that children solve the Hooks task easily, after an adult demonstrates how to make a pipecleaner hook. This demonstration changes the Hooks task from an ill-structured problem to a well-structured problem, by providing children with the necessary information about how to transition from the goal to the end state. Children solve this well-structured version of the problem easily.

In addition, in a version of the Hooks task where they were shown a premade hook and given bending practice, older children were more likely to solve the Hooks task than if they only had bending practice (Cutting et al, 2014). Seeing a target tool and having the pliant nature of the test materials highlighted to them provides children with information, albeit incomplete, about how they might transform from the goal to the end state. As such, the problem was more ‘well-structured’ and for the older children, this was enough to boost performance, although not enough to make the problem trivially easy.

It could be argued that the versions of the Hooks task completed by the corvids were not truly ill-structured, in that they were provided with information about how to transform from the start to the goal state. For example, Betty had previous experience using premade hooks on the task apparatus (Weir et al, 2002) and the rooks had experience of using premade hooks from other materials too (Bird & Emery, 2009). Children on the other hand, did not have any exposure to premade hooks in the task context (Beck et al, 2011). This may go some way to explaining children’s surprisingly poor performance, in comparison to corvid species.

It is difficult to make the Hooks task a more “well-structured” problem, without removing to some extent the child’s need to innovate. Providing them with clues about how to arrive at the solution, for example via a tool manufacturing demonstration, or by allowing them to use a premade hook on the test apparatus, takes away their need to spontaneously innovate the solution to the task for themselves. The first series of experiments in Chapter 2 of this thesis begins by levelling the playing field for children and corvids on the Hooks task, an obvious gap in the existing literature. Chapter 2 explores how prior experience with premade hook tools affects Hooks task performance. To some extent, this makes the problem more “well-structured”, by providing information to children about how to move from the goal to the end state. Most of the remaining work in this thesis focuses on ways in which we might be able to promote children’s success on the Hooks task, without giving them clues about how to arrive at the solution. This will provide further insight into whether the ill-structured nature of the Hooks task is a sufficient explanation for children’s difficulties in solving it.

1.5 Can Children Be Supported to Innovate Tools?

Most of the studies of children's tool innovation to date have been concerned with identifying the limiting factors on children's performance. Thus far, executive functions, task pragmatics, permission, environment and a sense of ownership over materials have failed to explain children's difficulty in spontaneously innovating the solution to the Hooks task. An alternative approach to studying children's tool innovation, is to explore the conditions under which children are more likely to succeed. Much of the work in this thesis explores whether children can be supported to innovate tools, without having to be given any clues or prompts about how to solve the task.

To date, children's performance on the Hooks task has painted a fairly dismal view of young children's propensity for tool innovation. Children's performance has been shown to improve with age, with children becoming proficient at this task around 9 years of age (Beck et al, 2011). One goal of this thesis is to begin to explore whether young children's difficulties on the Hooks task are true reflections of their tool innovation capacity capacities. It is possible that previous versions of the Hooks task have not been optimal for eliciting children's tool innovation. A second goal was to investigate whether can children be supported to solve the Hooks task, without being given explicit clues about how to solve it. By beginning to explore the circumstances under which children are successful, we can also begin to piece together what makes tool innovation problems so difficult for them. In the following sections, I will briefly outline some of the different ways in which we might boost children's tool innovation. These are discussed in more details in the relevant chapters.

1.5.1 Prior Experience

Children's exploratory play allows children to learn about the world, test hypothesis and gain causal knowledge about objects and relations which they can call upon in the future

(Gopnik, 2012). One of the great challenges of empirical research with children and tools is the difficulty with controlling the past experiences that children have had with tools and test materials such as craft items, pipecleaners etc.

In the case of corvid research on the Hooks task (Weir et al, 2002; Bird & Emery, 2009), corvids' experience of the apparatus and test materials could be more closely controlled. In the case of Betty, the New Caledonian Crow who spontaneously made a hook from a piece of garden wire, she had previously seen and used a premade hook of the same material successfully on to retrieve the bucket. The rooks also had experience using premade hook tools on the task, although the hooks used were of a different material to those which they went on to make (Bird & Emery, 2009). Since research with corvids provided the basis for studying tool innovation with children, it seems surprising that we do not yet know the effect that such previous experience with premade tools would have on children's likelihood to make their own hook tool when they need it to solve the Hooks task for themselves. In Chapter 2, the effect of prior experience with premade tools, both using them and seeing them, is explored.

1.5.2 Directing an Adult

Private speech, or self-talk refers to the phenomenon whereby children talk to themselves or provide a commentary whilst completing a task. Vygotsky (1978) suggested that private speech helps with the self-regulation of children's cognition and behaviour, which is supported by studies with that show children's private speech increases as tasks increase in difficulty (Duncan & Pratt, 1997; Fernyhough & Fradley, 2005). Children's private speech has been implicated in children's creativity. Children who demonstrated more coping, reinforcing and problem-solving private speech also had higher creativity scores (White & Daugherty, 2009). It has also been suggested that private speech might facilitate children's problem solving. Fernyhough & Fradley (2005) found that 5- and 6-year-old children who produced more private speech, were better at the Tower of London (ToL) task (solving it quicker and in fewer moves).

In addition to evidence suggesting that spontaneous production of overt private speech is related to problem solving, there is also evidence that actively encouraging participants to produce verbalisations can improve task performance. For example, prompting children to explain how a mechanical toy worked made them more likely to be able to identify which pieces were missing when it was later broken and they were required to fix it (Legare & Lombrozo, 2014).

At present, the effect that encouraging children to produce explanations could have on children's performance on tool innovation problems is unknown. Drawing on findings that encouraging children to produce explanations improves problem-solving, in Chapter 3 I explored whether encouraging young children to explain how to solve the Hooks task, by directing an adult experimenter, made them more likely to innovate the solution.

1.5.3 Spatial Priming

Whenever we remember our past, speculate about future events or imagine alternative outcomes, we are constructing mental representations that are psychologically distant. Experiences and objects can be psychologically distant along different dimensions, including time, space and hypotheticality. For example, when I think about objects in space, I am thinking about a spatially distant object when compared with the bottle of water placed immediately in front of me. When I think about the time I visited the beach as a child to collect shells compared to the time five minutes ago that I sat and drank a cup of tea, I am thinking about experiences which are psychologically distant in terms of time.

Researchers have studied the effect of priming psychological distance on children's creativity (Liberman, Polack, Hameiri & Blumenfeld, 2012). They found that priming spatial distance made children more fluent and original on subsequent tests of creativity. They argue that priming children to think about things which are more spatially distant from the here and now, promotes abstract thinking and therefore boosts creativity. In Chapter 5, I explore how priming psychological distance might affect children's likelihood to innovate tools.

1.5.4 Analogical Reasoning

When we reason by analogy, we make comparisons and draw on our knowledge and past experiences to help us to make decisions, judgements and solve problems. There is evidence that our ability to engage in this style of reasoning develops gradually across childhood, with a shift in this style of thinking around five years of age (Ratterman & Gentner, 1988). This shift in analogical thinking corresponds with one change we observe in children's tool innovation performance (Beck et al, 2016). It is likely that solving the Hooks task demands at least some analogical thinking. Children need to draw upon their knowledge of the task materials and physical properties of the task, recall their past experiences, and apply this to coordinate a solution to the problem.

To date, no study has investigated directly how children's analogical reasoning and tool innovation might be related. One series of studies has looked at how readily children can transfer acquired tool knowledge across time and different variations of a problem based on the Hooks task (Beck, Cutting, Apperly, Demery, Iliffe, Rishi & Chappell, 2014). In the first study, children who failed to spontaneously make a hook for themselves on the Hooks task, were given an adult demonstration of how to make a pipecleaner hook. These children were significantly better at making a hook when they encountered the Hooks task three months after they first attempted it. They showed that their tool-making knowledge, which they had gained by observing the experimenter make a hook, was robust when this knowledge was to be applied to the same task three months later.

Beck and colleagues (2014) next looked at whether children transfer their tool-making knowledge when faced with new but similar problems. In the second study, children who failed the Hooks task were given a hook-making demonstration by the experimenter and were permitted another go at the task. The apparatus was then cleared away and children were presented with new versions of the task. The new versions of the Hooks task differed only in their surface characteristics, but ultimately required the same solution. For example, the colour of the pipecleaner was changed from cream to red to purple and the shape of the tube from round to square. Children still needed to make a hook tool from a pipecleaner to retrieve an out of reach bucket with a hoop attached. In one version the bucket to be retrieved was round and blue with a hoop attached, whilst the other version used a square, yellow bucket. Younger children transferred their knowledge to new versions of the task somewhat, around half of 3- to 5- year-olds were successful on later trials. Older children almost always transferred their knowledge, 5- to 6- year-olds performed near ceiling on subsequent trails with new versions of the task. A third study showed that children could not transfer their knowledge of the hook tool required to make a hook from a different material. 5- to 7- year-olds did not transfer their knowledge of making pipecleaner hooks to make a hook from wooden dowel to solve the Hooks task.

Taken together, these studies demonstrated that knowledge that young children gain about tool making is somewhat robust. They can draw upon their knowledge and use it in the future, at least 3 months later, when it is applied to the same problem. Older children were also good at transferring their knowledge and generalising it to new, similar problems but not to new tool-making materials. Younger children transferred their knowledge to new problems less often. These findings suggest that the ability to draw upon tool-making knowledge and be able to use this to solve novel problems is something which is developing in middle childhood. Beck and colleagues posited that this is related to development in children's analogical reasoning.

The findings of Beck et al (2014) suggested that children do not reliably transfer tool making knowledge to novel situations. This might partially explain why some children fail the Hooks task. Children might struggle to draw upon their relevant knowledge and experiences to help them to innovate a tool for themselves. It is possible that those children who do succeed at the Hooks task have superior analogical reasoning ability. However, it might also be the case that by encouraging children to engage in analogical style thinking, we might see better performance on the Hooks task. Some research suggests that children are better at solving problems when they have been encouraged to reason by analogy (Chen and Daehler, 1989). In Chapter 6, I explore this idea further.

1.6 This Thesis

Our ability to innovate tools is an important aspect of human culture and as such, deserves attention. To date, attempts to identify limiting factors in children's tool innovation ability have not been telling. At present, our understanding of children's tool innovation is that it remains a difficult problem for the majority of children until at least around 8 years. However, for some children this ability emerges much earlier, suggesting that tool innovation is within even young children's capacity. With this in mind, this thesis had two aims. First, to look at the possibility that there is a personal characteristic, such as creativity, which might underlie individual differences in children's tool innovation ability. Second, it aimed to discover whether children can be supported to innovate tools from an earlier age and whether this can provide us with an insight into the possible constraints upon children's tool innovation. In Chapter 2 I strived to make the methodologies used in the corvid and human children literature more consistent. Children’s prior experiences with premade tools were manipulated to test what effect this might have on future innovation. In Chapter 3 I investigated whether young children were able to bring to mind the solution to the Hooks task, when they were no longer required to make the tool for themselves but had to direct an adult to do so. In Chapter 4 I looked for a direct relationship between children’s creativity, measured by divergent thinking, and tool innovation. In Chapters 5 and 6 I tested the possibility that children’s mindset can affect their likelihood to innovate tools. In Chapter 5 I explored how spatial priming might influence innovation. In Chapter 6 I examined whether encouraging children to engage in analogical problem-solving would increase their chances of solving the Hooks task. Finally, in Chapter 7 I summarise the findings of this thesis and discuss their implications as well as possible directions for future research. For reference, a glossary of definitions of key terms used throughout this thesis can be found after the list of contents.

Chapter 2

The effect of prior experience on children's tool innovation.

The following chapter is published, largely in its current form as[1]:

Whalley, C.L., Cutting, N., & Beck, S.R. (2017) The effect of prior experience on children's tool innovation. *Journal of Experimental Child Psychology*, 161, 81-94.

[1] *I took the lead role in coming up with the original idea for the studies, study designs, all data collection, data analysis, interpretation and write-up.

2.0 Abstract

Spontaneous tool innovation to solve physical problems is difficult for young children. In three studies, I explored the effect of prior experience with tools on tool innovation in children aged 4- to 7- years (N=299). We also gave children an experience more consistent with that experienced by corvids in similar studies, to enable fairer cross-species comparisons. Children who had the opportunity to use a premade target tool in the task context during a warm-up phase were significantly more likely to innovate a tool to solve the problem on the test trial, compared to children who had no such warm-up experience. Older children benefited from either using or merely seeing a premade target tool prior to a test trial requiring innovation. Younger children were helped by using a premade target tool. Seeing the tool helped younger children in some conditions. We conclude that spontaneous innovation of tools to solve physical problems is difficult for children. However, children from 4 years can innovate the means to solve the problem when they have had experience with the solution (visual or haptic exploration). Directions for future research are discussed.

Keywords: tool use, innovation, problem solving, cognitive development

2.1 Introduction

Tool use is considered to be a hallmark of human cognition, with our substantial technological accomplishments unrivalled by any non-human animal species. Observations of infants and children demonstrate their impressive competence in terms of their tool use and knowledge. From around 2 years of age, children show insight into the function of tools (Casler & Kelemen, 2005) and anticipate the target of a tool-use action (Paulus, Hunnius & Bekkering, 2011). Three year olds reliably copy tool use from peers (Hopper, Flynn, Wood & Whiten, 2010) and are capable of transmitting a tool-use action across multiple generations (Flynn & Whiten, 2008; Hopper et al., 2010). It is surprising then, that despite being proficient tool-users, children appear to struggle to innovate tools; that is to make a novel tool to solve a task, without prior training (Beck, Apperly, Chappell, Guthrie & Cutting, 2011; Cutting, Apperly & Beck, 2011; Cutting, Apperly, Chappell & Beck, 2014; Hanus, Mendes, Tennie & Call, 2011; Nielsen, Tomaselli, Mushin & Whiten, 2014; Sheridan, Konopasky, Kirkwood & Defeyter, 2016; Tennie, Call & Tomasello, 2009).

Recent research into children's tool innovation was motivated by studies with corvids. Betty, a captive New Caledonian crow, spontaneously manufactured a hook from a straight piece of wire, to retrieve a wire-handled bucket from a transparent tube (Weir, Chappell & Kacelnik, 2002). Researchers were investigating whether crows could choose the correct tool to solve a task and, on a task requiring a hook, had given them a hooked and a straight piece of wire. When one crow flew off with the hooked tool, Betty bent the straight piece of wire to make her own hook, despite not being shown how to make tools previously. In a later experiment, Betty continued to make functional hooks on the majority of trials when given only straight pieces of wire. New Caledonian Crows have been directly observed making and using tools in the wild (Hunt & Gray, 2004; Rutz, Sugasawa, van der Wal, Klump and St Clair (2016), although not from wire or wire-like materials. However, similar findings have been replicated by Bird and Emery (2009) with captive rooks, a species which do not use tools in the wild. They were also able to select and manufacture the correct tool to solve the hook-making task used by Weir and colleagues (2002). Thus, it is even more surprising that children younger than 8 years demonstrate difficulty with similar problems requiring tool-innovation.

In a paradigm adapted from the corvid literature, children were able to choose the appropriate tool to solve a problem requiring a hook (Beck et al., 2011). From 4 years old, children were significantly more likely to pick up a hooked pipecleaner than a straight one, when their goal was to retrieve a handled bucket containing a sticker reward from a tube. However, when other children were given a straight pipecleaner which required bending into a hook shape to retrieve the bucket, children younger than 5 years rarely solved the task. Performance improved with age and it was not until age 8 years that approximately half of children passed the task. Interestingly, most children found manufacturing a tool (making a tool following adult demonstration) comparatively easy. This finding appears consistent across cultures. Western and indigenous children of South Africa show a similar pattern of tool innovation performance; innovating a tool independently to solve a physical problem is difficult for children aged 3- to 5-years, while manufacturing a tool following an adult demonstration is significantly easier (Nielsen et al., 2014).

Beck and colleagues (2011) noted that children's knowledge of tool function and ability to manufacture tools emerges significantly earlier than their ability to innovate tools. Given the findings from tasks involving corvids, children's difficulty with tool innovation has been met with curiosity. Since many non-human species are known to use tools (Seed & Byrne, 2010) it is the human propensity for tool *innovation*, and the complex technologies that have arisen thanks to it, that sets us apart from non-human species. Findings such as these raise bigger questions surrounding human cognitive architecture. It is important to better understand those processes that we might share with non-human animals and those that may demonstrate human uniqueness (Shettleworth, 2012).

Cross-species comparisons between human children and non-human animals are often made (e.g. Engelmann, Herrmann & Tomasello, 2012; Beck et al., 2011, Cheke, Loissel & Clayton, 2012; Taylor et al., 2014). However, caution is required. To truly understand how human children, differ from other species, in this case corvids, it is vital that studies are methodologically sound and fair to both species (Boesch, 2007; Shettleworth, 2012). When experimental procedures systematically differ, the value of cross-species comparisons is compromised. To date, the experiences of children and corvids on versions of the hook-making task have not been consistent.

Specifically, the experience of the corvids and children prior to attempting the hook-making task were inconsistent. Corvids had already seen and had the opportunity to use a premade hook: made either from the same material as was available for tool-making (wire, Weir et al., 2002) or a different material (wood, Bird & Emery, 2009). Some children had not seen a pipecleaner hook previously within the task (Beck et al., 2011) and others saw a hook but did not have the opportunity to use it (Cutting et al., 2014). The effect and potential advantage that such an experience might have on subsequent tool innovation in children is yet to be determined.

Cutting and colleagues (2014) suggest that certain pre-test experiences can promote tool innovation on the hook-making task. In their study, 4- to 6-year-olds were shown a premade example of a pipecleaner hook (target tool demonstration). Half of the children also had the pliable nature of the test material (pipecleaners) highlighted to them, via a ‘bending practice’. It was found that 5- to 6-year-olds were significantly more likely to solve the hook-making task if they received both a target tool demonstration and bending practice compared with only seeing a target tool demonstration. This suggests that seeing the correct tool required to solve a problem does not make tool innovation problems trivially easy for children. Unlike the corvids, children in these studies were not permitted to use the premade target tool prior to attempting the hook-making task.

The purpose of the current series of experiments was two-fold. First, we sought to further explore the effect of prior experience on children's tool innovation. Second, we aimed to draw fairer cross-species comparisons of tool innovation between corvids and children. In three studies, the role of prior experience on children's ability to innovate a hook tool to solve the hook-making task was investigated.

In Study 1 we explored how children performed on the hook-making task, given the same pre-test conditions as corvids; that is, the opportunity to use a pre-made pipecleaner hook. Children, but not corvids, have previously been presented with non-functional, distracter materials during the hook-making task, such as string (Beck et al., 2011; Cutting et al., 2014). Therefore, no distracter items were included in these studies and children were only presented with pipecleaners. Some corvids were also given multiple trials at the hook-making task, although performance was not observed to improve or deteriorate over time. Still, it seems important that the possibility of improved or changed performance over time is explored in children. Therefore, the first study included three trials to explore this possibility and to match more closely the experimental methodology of corvids. We did not give children the full 17 trials used in the original corvid study, because we judged this too many for children to cope with. Before attempting the hook-making task, half of the children completed a hook-using phase, where they were given the opportunity to use a premade pipecleaner hook on the bucket and tube apparatus. The hook-using phase emulates the condition used by Weir and colleagues (2002) where corvids were given a hooked and a straight piece of garden wire.

2.2. Study 1

2.2.1 Method

2.2.1.1 Participants

The participants were 28 children aged 4 or 5 years (mean age = 4 years and 6 months [4;6], range = 4;2 - 5;1) and 30 children aged 6 or 7 years (M = 6;7, range = 6;3 - 7;1), recruited from a mainstream school in the UK. The ethnic composition of the sample was 85% Caucasian, 10% Black, and 5% Asian. Two additional children were excluded from analysis due to retrieving the bucket without making a hook or other functional tool.

2.2.1.2 Materials

The apparatus was a transparent plastic tube (22cm length; opening 5cm in diameter) attached to a cardboard base (Fig.1). At the bottom of the tube there was a small bucket containing a sticker. The bucket had a wire handle that required a hook in order to retrieve it from the tube. Tool-making materials were 30cm pipecleaners.

Fig. 1. *Apparatus for Hook-making task.*

2.2.1.3 Procedure

The study comprised a hook-using phase and an innovation phase. Children were systematically assigned to either the Experimental condition or the Control condition by their class list. They were told by their class teacher that they would be playing a game and must not discuss the game in the class as it would spoil the surprise for the other children. Children completed the experiment in a quiet area of the school library with a female experimenter. A second female coder (NC) was present during one of four testing days, to ensure reliability of coding success/failure on the hook-making task. There was 100% inter-observer agreement.

Children in the Experimental condition first completed the hook-using phase. A 30cm straight pipecleaner and a 30cm pipecleaner bent at one end to form a hook were placed next to the apparatus in front of the child. They were told “If you are able to get the sticker out of the tube, then you can keep it”. Children had up to one minute to complete this phase and neutral prompts were given by the experimenter where necessary.

All children completed the innovation phase. This followed the hook-using phase for those in the Experimental condition and was the only phase for those in the Control condition. During the innovation phase children were presented with the same bucket/tube apparatus and a 30cm straight pipecleaner only. They were told “If you can get the sticker out of the tube, then you can keep it”. All children received three trials. In the first trial, children were allowed up to one minute to attempt the task. The experimenter then re-set the task for two further 30-second trials. If children failed to innovate a hook after the third trial, the experimenter provided a demonstration of how to make a hook and kept it herself. Children were then encouraged to have another attempt to retrieve the sticker, using their own materials. Only two children failed to make a hook following an adult demonstration. In these cases, children were given the experimenter’s premade hook and used this retrieve the bucket.

2.2.2 Results & Discussion

Criteria for success on the innovation phase, here and in all further experiments, were making a hook tool and using it to retrieve the bucket from the tube, n.b. all children who made a hook were able to retrieve the bucket from the tube. There were no significant effects of gender on performance in trials 1, 2 or 3, Fisher's Exact Test, lowest *p* = 0.267. Therefore, data were combined across gender for all analyses.

Table 1. *Performance across trials in Study 1 Test Phase.*

Age group (years)	Condition	N	Number of children succeeding		
			Trial 1 (%)	Trial 2 (%)	Trial 3 (%)
4-5	Experimental	15	9 (60)	9 (60)	8 (53.33)
	Control	13	0 (0)	1 (7.69)	2 (15.38)
6-7	Experimental	15	14 (93.33)	13 (86.67)	15 (100)
	Control	15	9 (60)	7 (46.67)	7 (46.67)

First, we analysed whether the hook-using phase was successful in changing children's experience in the Experimental condition. In other words, did children use the hook prior to attempting the innovation phase? Four- to five-year-olds were significantly more likely than chance to pick up the hooked pipecleaner first: 15 out of 15 children choosing the hook first, (binomial test, $p < .001$). A binomial test revealed the same pattern for 6-to 7- year-olds, 12 out of 15 children chose the hook first, ($p = .035$). The 3 children who picked up the straight pipecleaner first, went on to use the hooked pipecleaner afterwards. Therefore, children in the hook-using phase did indeed use the hook before attempting innovation.

Second, the effect of age group on performance during the innovation phase was analysed. Six- to seven-year-olds in the Control condition were significantly more likely to pass the innovation phase than four- to five-year-olds, Fisher's Exact Test, $p = .018$. However, in the Experimental condition there was no significant difference in performance related to age, Fisher's Exact Test, $p = .080$.

Of most interest was whether condition affected performance in the innovation phase and therefore likelihood to innovate a functional hook tool. Since a significant effect of age was found in the control group, age groups were analysed separately when comparing performance by condition. The percentage of children who passed each trial is shown in Table 1. Condition had a significant effect in trial 1 (4- to 5-year-olds: Fisher's Exact Test, $p = .001$, 6- to 7-year-olds: $\chi^{2yates}(df = 1, N = 30) = 7.350$, $p = .007$). At trial 2 condition had a significant effect on performance of 4- to 5-year-olds (Fisher's Exact Test, $p = .006$), but the effect marginally failed to reach significance for 6- to 7-year-olds: $\chi^{2yates}(df = 1, N = 30) = 3.750$, $p = .053$). At trial 3, condition had a significant effect on performance of 6- to 7-year-olds, Fisher's Exact Test, $p = .002$, but the effect marginally failed to reach significance for 4- to 5-year-olds, Fisher's Exact Test, $p = .055$. However, considering the significant results across all other trials, this borderline finding will be treated as if significant.

To determine whether performance changed over time, McNemar tests were used to compare success levels between trials for each age group (trial 1 vs trial 2, 4- to 5-year-olds $p > .999$; 6- to 7-year-olds $p > .999$; trial 2 vs trial 3, 4- to5-year-olds $p > .999$; 6- to 7-year-olds $p = .500$; trial 1 vs trial 3, 4- to 5-year-olds $p > .999$; 6- to 7-year-olds $p = .500$). Therefore, children's performance appeared to neither improve nor deteriorate over time.

Finally, tool manufacture was easy for children. Of those children who failed to innovate a hook independently in any of the three test trials, 26 out of 28 went on to successfully make a hook following an adult demonstration.

The results from Study 1 demonstrated that children, who had been given the opportunity to use a hook tool prior to being required to make one of their own, were at a significant advantage over those children who had no such experience. Therefore, using a hook tool facilitated children's subsequent tool innovation, so much so that younger children performed as well as older children. These results suggest that, like corvids, children are able to succeed on the hook-making task having used a hook previously.

Next, I aimed to disentangle what aspect of the warm-up phase was facilitating subsequent innovation. There are at least two obvious factors which could be independently or collaboratively facilitating innovation. Children first have to *choose* the hook as the correct tool and reject the straight pipecleaner. Second, they *use* the hook on the hook-making task. I designed a second experiment to investigate whether choosing the hook and rejecting the straight pipecleaner was an important element of the warm-up phase or whether simply using a premade pipecleaner hook was sufficient. It may be that being able to contrast two tools (a straight and hooked pipecleaner) helps children to identify what is functional about the target tool. We know that children aged from 4 years successfully choose a hooked tool over a straight one to solve this task (Beck et al., 2011). If this is the case, I expect children who choose a hook to outperform children who are just given a hook to use on the hook-making task. Alternatively, the additional demand of having to choose between two tools may be more taxing for children (perhaps through working memory demands) and this may reduce performance on the subsequent hook-making task.

2.3 Study 2

2.3.1 Method

2.3.1.1 Participants

Twenty-eight children aged 4 or 5 years (M = 4;9, range = 4;5 - 5;4) and 23 children aged 6 or 7 years (M = 6;10, range = 6;5 - 7;4) were recruited from the same school as Study 1 and made up the final sample. None of these children had taken part in the first experiment. The ethnic composition of the sample was 78% Caucasian, 10% Black, 8% Asian, and 4% other/unknown. Nine additional children were excluded from analysis due to retrieving the bucket without making a hook or other functional tool.

2.3.1.2 Procedure

All participants were presented with the plastic tube and bucket apparatus used in Study 1. Children were systematically allocated by their class list to one of two conditions. In the Hook Use condition, a premade pipecleaner hook only was placed next to the tube apparatus (Fig. 2). In the Tool Choice condition, a 30cm straight pipecleaner and a premade pipecleaner hook were placed next to the tube apparatus (Fig. 3). In both conditions, children were then given up to a minute to try to retrieve the bucket from the tube.

Fig. 2. *Apparatus for Tool-Choice condition in Study 2.*

Fig. 3. *Apparatus for Hook Use condition in Study 2.*

Having completed either the Hook Use or the Tool Choice phase, all participants then completed the same test phase as used in Study 1. Since no difference in performance across trials was observed in Study 1, children were only given one attempt at the test phase.

2.3.2 Results & Discussion

All children successfully used a premade hook tool in both conditions. There was no significant effect of gender on performance in either condition or age group, Fisher's Exact tests, lowest $p = .236$. Therefore, data were combined across gender for subsequent analysis.

Age group did not have a significant effect on performance in the test phase in either the Tool Choice condition, Fisher's Exact Test, $p > .999$, or Hook Use condition, $\chi^2(df = 1, N = 26) = 1.330$, $p = .249$.

Table 2. *Performance during the test phase in Study 2.*

Age group (years)	Condition	n	Number of successful children (%)
4-5	Choice	14	10 (71.43)
	Use	14	9 (64.29)
6-7	Choice	11	8 (72.73)
	Use	12	5 (41.67)

Finally, Table 2 shows the percentage of children who passed the test phase in each condition. Analyses were run to investigate whether condition affected innovation. First, analysis was run for each age group separately. Condition did not affect performance on the test phase for younger children, Fisher's Exact Test, p > .999, or older children, Fisher's Exact Test, $p = .214$. Since age did not affect performance in this sample, a Chi square analysis was also conducted with age groups combined, however condition still showed no significant effect on innovation, $\chi^2(df = 1, N = 51) = 1.797$, $p = .249$.

Study 2 sought to explore what it was about the warm-up phase in Study 1 that facilitated tool innovation. Regardless of whether they chose and used a pipecleaner hook or only used a pipecleaner hook in their first phase, children were just as likely to innovate a hook in the test phase. This suggests that it is using the hook rather than the choosing element of the warm-up phase that improves children's tool innovation. In other words, rejecting the non-functional tool (straight pipecleaner) in the choice phase does not seem to improve children's likelihood of innovating a hook in the test phase. Rather, the opportunity to use a functional hook tool on the hook-making task seems to promote children's tool innovation.

The findings from Studies 1 and 2 are especially interesting since Cutting and colleagues (2014) found that showing children a pipecleaner hook was not sufficient to help them to innovate one of their own afterwards. In their study, Cutting and colleagues showed children a premade pipecleaner hook only if they failed to innovate a hook on the hook-making task, and then allowed them another go at the task. Half of these children were given pipecleaner bending practice, whilst the other half were not. It was found that only older children, who were also given the opportunity to manipulate the materials beforehand, benefited from a target tool demonstration.

Cutting and colleagues (2014) were focussing on children's performance after different aspects of the hook-making task were highlighted to them and how they could retrieve and coordinate this information to solve the task. As such, the analysis focused on performance between conditions rather than stages. However, it is possible that for some children, seeing a target tool drove their subsequent innovation.

This leaves open the question of whether seeing a target tool is as helpful as the opportunity to use a target tool in terms of likelihood of going on to solve the hook-making task. Children from age 3 and 4 years have been shown to demonstrate different strategies of exploration of materials for different tasks. For example, they used visual exploration to determine which spoons were the correct size to transport sweets, but chose haptic exploration to decide which sticks, of varying rigidity, were suitable to stir sugar and gravel (Klatzky, Lederman & Mankinen, 2005). It is yet to be made clear whether children find visual or haptic exploration of premade tools equally useful, or not, in the context of tool innovation or the hook-making task. If the key information that children extrapolate from a hook demonstration is regarding its shape, one would expect visual demonstration to be sufficient. However, if the information children require is regarding some other physical property of the pipecleaner, e.g. flexibility, rigidity, one might expect that haptic exploration would be more beneficial.

In Study 3 I sought to compare the effect of seeing versus using a premade hook on performance on the hook-making task. In Studies 1 and 2 children were given the opportunity to use a hook before attempting the task.

Another factor is whether children benefit more from being given solution-relevant information before or after they encounter the problem to be solved. In studies 1 and 2 children had only used a pipecleaner hook before they attempted the hook-making task, which proved beneficial to both younger and older children. In a previous study, children (and apes) were either shown the location of tools that they could choose to use to solve a problem before or after they had seen the task they were going to solve (Martin-Ordas, Atance & Call, 2014). Younger children found it easier to locate the tools to solve the problem after they had seen the task they would need to solve. These findings suggest children are sensitive to the timing of relevant information when engaging in tool-use tasks and the same may be true of tool-innovation tasks. Given the findings of Martin-Ordas and colleagues (2014) we might predict that younger children would benefit more from being given solution relevant information after already attempting the hook-making task. Hence, in

Study 3 I also manipulated the timing of the experience children were given (before or after having attempted the task).

2.4 Study 3

2.4.1 Method

2.4.1.1 Participants

The participants were 94 children aged 4 or 5 years (M = 4;7, range = 4;3 - 5;2) and 96 children aged 6 or 7 years (M = 6;7, range = 6;3 - 7;2) from two mainstream schools in the UK. The same proportion of children from each school were present in each age group. The ethnic composition of the sample was 89% Caucasian, 5% Black, and 6% Asian. None of these children had taken part in the previous experiments.

2.4.1.2 Procedure

Children were presented with the same bucket and tube apparatus from the previous experiments. As per the 2 x 2 design, children were systematically assigned by class list to one of four conditions: See Before, See After, Use Before, or Use After. All children completed the standard test phase (hook-making task) from the previous experiments and were given the same instructions. The experimenter told them "If you can get the bucket out of the tube then you can keep the sticker." However, the experience which the children had before and after attempting the test phase, varied per condition.

In the See Before condition, children were presented with the bucket and tube apparatus. The experimenter then said "Look at this" and showed them a premade pipecleaner hook. The experimenter then removed this from sight, said "Here is something that might help you" and placed a straight pipecleaner next to the apparatus. Children were then given one minute to attempt the hook-making task.

In the See After condition, children first attempted the hook-making task (pre-demonstration phase). Children who failed to innovate a pipecleaner hook and retrieve the bucket were encouraged to put down their materials. The experimenter then showed them a premade pipecleaner hook, said “Look at this” and gave a new straight pipecleaner if necessary. Children then attempted the hook-making task for a second time.

In the Use Before condition, children were presented with the bucket and tube apparatus and a premade pipecleaner hook. They were allowed up to one minute to attempt the task with the materials given. All children successfully retrieved the bucket using the premade pipecleaner hook. Children then attempted the hook-making task.

In the Use After condition, children first attempted the hook-making task (pre-demonstration phase). Children who failed to innovate a pipecleaner hook and retrieve the bucket were encouraged to put down their materials. Pipecleaners were removed. The experimenter then gave them a premade pipecleaner hook and said “Here is something that might help you”. Children were encouraged to have another go at the task for up to one minute. Once more, all children successfully retrieved the bucket using the premade pipecleaner hook. Children then attempted the hook-making task for a second time.

As previously, if children failed to make a hook on their second (After conditions) or only (Before conditions) attempt at the hook-making task, the experimenter demonstrated how to make a pipecleaner hook and allowed the child to have another go at the task.

2.4.2 Results & Discussion

There was a significant overall effect of gender on performance in 4- to 5-year-olds, with females performing better than males, χ^{2Yates} (df = 1, N = 94) = 4.115, p = .042, ϕ = 0.231. However, there was no significant effect of gender on performance in 6- to 7-year-olds, χ^{2Yates} (df = 1, N = 96) = 0.686, p = .408. Since no previous effects of gender have been observed on these tasks, and this difference was only present in one age group, the result will not be discussed further here.

Older children performed significantly better than younger children in the Use After condition, Fisher's Exact Test, p = .030, and the See Before condition, χ^2 (df = 1, N = 47) = 6.139, p = .013, ϕ = 0.006. However, there were no significant differences in performance related to age in either the See After condition, χ^2 (df = 1, N = 48) = 2.521, p = .112, or Use Before condition, χ^2 (df = 1, N = 48) = 1.137, p = .286.

Table 3. *Performance across conditions in Study 3*

Age group (years)	n	Condition	Number of successful children on test phase (%)
4-5	24	Use Before	17 (70.83)
	23	Use After	15 (65.22)
	23	See Before	7 (30.43)
	24	See After	14 (58.33)
6-7	24	Use Before	21 (87.50)
	24	Use After	22 (91.67)
	24	See Before	17 (70.83)
	24	See After	20 (83.33)

Of most interest was whether condition affected performance. Table 3 shows performance across conditions for each age group. Children in the After conditions (Use After, See After) who passed during the pre-demonstration phase were included in the analysis. This is to match children in the Before conditions who may have passed, regardless of the opportunity to see or use a hook and could not be identified. A total of 8 children in Use After condition (two 4- to 5-year-olds and six 6- to 7-year-olds) passed during the pre-demonstration phase and 10 children in the See After condition (two 4- to 5-year-olds and eight 6- to 7-year-olds) passed during the pre-demonstration phase.

I first looked at whether the timing of when information relevant to the hook-making task was given affected performance on the hook-making task. There were no significant differences between performance in Before and After conditions, in 4- to 5-year-olds, $\chi^{2 Yates}$ (df = 1, N = 94) = 0.692, p = .405, or 6- to 7-year-olds, $\chi^{2\ Yates}$ (df = 1, N = 96) = 0.675, p = .411. Second, I looked at whether there was any difference in performance on the hook-making task, related to whether children were in a 'Use' or 'See' condition. There were no significant differences in performance of 6- to 7-year-olds between the Using and Seeing conditions, $\chi^{2 Yates}$ (df = 1, N = 96) = 1.875, p = 0.171. However, 4- to 5-year-olds performed significantly better in Use conditions compared to See conditions, $\chi^{2\ Yates}$ (df = 1, N = 94) = 4.326, p = .038, ϕ = -.236. I then looked at what was driving the difference between these conditions in 4- to 5-year-olds, using Bonferroni adjusted alpha level of 0.025 (.05/2). A continuity corrected Chi-square test indicated no significant difference in success between the Use After and See After condition, $\chi^{2 yates}$ (df = 1, N = 47) = 0.034, p = .853. However, children in the Use Before condition performed significantly better than those in the See Before condition, $\chi^{2 yates}$ (df = 1, N = 47) = 6.139, p = .013, ϕ = -.404.

Study 3 revealed no clear indication overall that either using or seeing a target tool is more beneficial than the alternative. Likewise, the timing of when clues or information relating to transformation from the start state to end goal does not appear to be important. In other words, being given tool-shape prior to attempting innovation is no more useful than being told the information having already had one failed attempt at the hook-making task.

However, younger children performed significantly better in the Use Before compared with the See Before condition, being more than twice as likely to succeed in the Use Before condition. This suggests that the Use Before condition was particularly beneficial for 4- to 5- year-olds in terms of facilitating innovation of a hook tool on the hook-making task. This complements the findings from Studies 1 and 2, in which younger children performed at similar levels to older children when they had the opportunity to use a premade hook tool prior to attempting the hook-making task. This can also be related to the findings of Cutting and colleagues (2014), who concluded that 4- to 5-year-old children experienced less benefit from seeing a target tool than 5- to 6-year-olds.

Older children performed well across conditions, with success levels greater than what might be expected given performance in the control condition in Study 1. The results suggest that using and seeing a premade target tool is useful for children of this age, whether this is before or after first attempting innovation. Younger children also performed well across conditions, when compared to performance in previous studies and in the control condition in Study 1. This suggests that some younger children were able to coordinate knowledge highlighted to them in order to innovate a hook tool.

2.5 General Discussion

Spontaneous tool innovation remains a difficult problem for many children aged below 8 years (e.g. Study 1, control group). Previous studies demonstrate that choosing the correct tool and tool manufacture following an adult demonstration are relatively easy for children from as early as 4 years (Beck et al., 2011). The current studies contribute to our understanding of what children find especially difficult about tool innovation. In Study 1, when children were given the opportunity to use a premade hook tool, making a hook of their own on subsequent trials was significantly more likely. Study 2 suggested that the *using* element of the pre-test experience in Study 1, rather than choosing/rejecting tools, seemed to be what was driving better performance on the hook-making task. Using a premade hook made it easier to solve the innovation problem in the future. This suggests that fundamental to children's success on the hook-making task was first interacting with the solution. This provides more evidence that the most difficult aspect of the hook-making task for children is bringing to mind the solution to the problem for themselves. However, it also demonstrates that children do not lack the understanding of how to transform the straight pipecleaner to a functional hook tool, without being explicitly shown how to do so in an action demonstration.

Finally, Study 3 provided further insight into children's performance on the hook-making task. Children across age groups and conditions performed better than expected on the hook-making task, compared with previous studies (Beck et al., 2011; Cutting et al., 2014) and children in the control group in Study 1. Younger children were most successful when they could use a premade tool before their first innovation trial. For older children, there was no significant difference between trials. In two conditions (Use Before and See After), there was no significant difference in success levels between younger and older children. These results highlight the benefit that younger children experience by being given information about the target solution. The results also suggest that the same information (e.g. seeing a hook before attempting the task) is not equally helpful for all children.

The results from Study 3 may reflect individual differences in children's learning preferences. For example, Flynn, Turner and Giraldeau (2016) recently suggested that 5 year olds could choose a learning strategy (social or asocial) for themselves that was effective for them. Children could either choose to attempt a task for themselves, or watch an experimenter attempt it first and then had their learning strategy choice either met or violated. Although children showed a strong preference overall to learn socially, unlike 3-year-olds, 5-year-olds were also efficient at solving the task under asocial conditions, when this strategy matched their indicated preference. In the context of Study 3, one might hypothesise that similarly, children show preferences for the types of information or opportunity for exploration offered (visual/haptic) and the timing of this information (before/after) attempting the task.

In Study 3 I concluded that using or seeing a premade tool was beneficial for older children in terms of solving the hook-making task later, with no single condition being significantly better than another. For younger children, using a hook was more beneficial than seeing a hook before attempting the hook-making task, but this difference was not present when the information was presented after their first attempt at innovation. This finding provides some support to the claims of Cutting and colleagues (2014), where it was concluded that older children benefitted from a target tool demonstration (alongside bending practice) whilst younger children did not. However, the focus of Cutting and colleagues (2014) was on performance between conditions rather than stages. On closer inspection, younger children in their study did appear to benefit from seeing a target tool demonstration, albeit not to the extent of the older children. Following a target tool demonstration, a further 23% (no bending practice) and 37% (bending practice) of children went on to innovate a hook tool of their own. In the present study, seeing a hook increased tool innovation from near floor (study 1) to 30 - 58% (see Table 3). This suggests that, for a significant number of 4- to 5-year-olds, seeing a premade hook facilitated their future hook tool innovation.

Cutting and colleagues (2014) concluded that 4- to 5-year-olds struggle to innovate both the solution (a hook) and the means (bending the pipecleaner) to solve the hook-making task. It was also concluded that although 5- to 6-year-olds were better at innovating the means to solve the task following a target tool demonstration and bending practice, spontaneous innovation of the hook tool solution remained difficult for the majority. Here, I suggest that Cutting and colleagues' conclusions may have been slightly pessimistic regarding younger children's capabilities. The majority of 4- to 5-year-olds in Studies 1 and 2 could innovate the means to solve the hook-making task, having had the chance to use (rather than just see) a premade tool. Younger children were also helped by seeing a target tool where performance was improved from near floor to 30 - 58% (see Table 3). I suggest that it is especially difficult for children aged 4- to 7- years to independently generate the solution to the problem: that they need a hook.

The current series of experiments allows us to comment for the first time on how the performance of children on the hook-making task compares with that of the corvids. When children were faced with similar pre-test experiences to that of the New Caledonian crow in the Weir and colleagues (2002) version of the task, they too were able to innovate a hook to solve the hook-making task. It would now be interesting to see how corvid species perform on tool tasks such as the hook-making task, without prior exposure to or experience with the target tool. Rooks had a different pre-test experience from that of children and crows (Bird & Emery, 2009). They were exposed to wooden hook tools prior to needing to make a wire hook of their own. In sum, they transferred the solution from the wooden hook tool and transferred this to a new material, when they made a wire hook on subsequent trials. Considering recent findings, this seems remarkable. Beck and colleagues (2014) found that 4- to 7-year-olds do not transfer their knowledge of manufacturing a pipecleaner hook when they are later required to make a hook from dowel (or vice versa) to solve a similar task (Beck et al., 2014).

In line with previous findings (Beck et al., 2011; Nielsen, 2014), I noted children's difficulty with spontaneous innovation of a tool to solve the hook-making task. None of the 4- to 5-year-olds and only a minority of 6- to 7-year-olds innovated a hook tool on their first attempt at the hook-making task, without prior experience of a premade tool. 'Betty' the crow demonstrated innovation of the means to solve the task but not innovation of the solution itself, due to her experience with a premade wire hook (Weir et al., 2002). However, spontaneous tool innovation has been reported in a cockatoo ‘Figaro’ (Auersperg, Szabo, von Bayern & Kacelnik, 2012). Given impressive reports of the abilities of certain non-human animal species, it remains intriguing that young children should experience such difficulty innovating tools to solve problems independently.

It is important to bear in mind that reports of tool-innovation in non-human animal species are often individual cases. For example, although Figaro the cockatoo could innovate a tool, other individuals either failed to use tools at all or showed components of tool making behaviour, which may have been the result of shared social experience with Figaro. Though this does not make the achievements of Figaro any less impressive, this does resonate with the literature examining children’s propensity for tool innovation. It appears, at least in the case of younger children (4- to 7-year-olds), that some children have capacity for innovation whilst others do not. A recent study has suggested that individual differences in divergent and creative thinking are not associated with tool innovation (Beck, Williams, Cutting, Apperly & Chappell, 2016). Future research efforts might explore whether the ability to innovate tools is related to other personal characteristics, personality traits or a set of cognitive abilities that promote innovative behaviour. In Chapter 4 of this thesis, I explore whether creativity, measured by their divergent thinking ability, is related to innovation.

Within the animal literature it is noted that to unravel the potential underlying cognitive mechanisms which support innovative tool manufacture, it will be necessary to control the developmental histories and experiences of subjects (Auersperg et al., 2012). This presents a challenge to the study of tool innovation in children, who come from a wide range of backgrounds with varied experiences. When studying children’s performance on such tasks, it is important to consider the wider socio-cultural context. Children at this age are likely to have received varied influence from parents and caregivers, including opportunity for exploration, feedback and availability of objects. This is especially true of the youngest children, who have spent less time in full-time state education. These factors may greatly influence a child’s likelihood to display innovative behaviour, both its onset and frequency (Tomasello, 1999). Future studies may find ways in which we can manipulate experience with objects and materials, to explore its effect on tool innovation.

Holyoak, Junn and Billman (1984) argue that analogical reasoning is an important mechanism for cognitive development, since analogy permits the transfer of knowledge and information from domains that are understood to those that are not. I propose that the hook-making task may require children to employ analogical reasoning, since they are required to make inferences about novel experiences, identify the relevant and useful information from target tool demonstrations and transfer what they have learnt to the innovation phase (for further discussion see Beck et al., 2014). It may be that those children with superior analogical reasoning abilities find it easier to use the information highlighted to them to pass the hook-making task. Future studies may seek to investigate whether children’s analogical reasoning is related to their tool innovation ability. In Chapter 6 of this thesis, I begin to explore how analogical reasoning might support children’s innovation.

Since, one of the main aims of these experiments was to draw comparisons with the corvid literature; the current findings are restricted to the results from one innovation task (hook-making). However, children's difficulty with spontaneous innovation has been demonstrated on tool innovation tasks such as the Floating Object Task (Hanus et al., 2011; Nielsen, 2013) and the Loop Task (Tennie et al., 2009). Here, children found it especially difficult to innovate the solution to the hook-making task: that they require a hook to retrieve the bucket from the tube. However, when given the opportunity to use the solution to the hook-making task, they could innovate the means to solve the task without prior training: they transformed the straight pipecleaner into a pipecleaner hook. It remains unclear why some children find tool innovation difficult, whilst others do not. A more complete picture of the developmental trajectory of tool innovation should be built, with further investigation into the levels of scaffolding required and conditions which might facilitate children's independent innovation on a wide range of innovation tasks.

Chapter 3

Are children better at tool innovation when directing an adult?

3.1 Introduction

In Chapter 2, I explored how prior experience can affect children's performance on the Hooks task as a measure of children's tool innovation. Previous literature has demonstrated that tool innovation is difficult for children, particularly younger children below 8 years of age (Beck et al, 2011; Cutting et al, 2011; Cutting et al, 2014; Frick, Clement & Gruber, 2017; Nielsen et al, 2014; Sheridan et al, 2016; Tennie et al, 2009). However, in Chapter 2 it was reported that 4- to 5-year-olds performed surprisingly well on the Hooks task under certain conditions. When children were given the opportunity to use a premade pipecleaner hook on the task, they were significantly more likely to innovate a hook of their own on a subsequent trial. Some children in this age group also benefitted from only seeing a premade hook tool, although additionally being able to use it showed the greatest increase in innovation.

These findings led us to question whether some studies of tool innovation have underestimated the ability of young children to innovate tools to solve novel problems. Previous studies suggest that children have some of the required knowledge to solve the task, when they are given hints about the potential solution. For example, the majority of 4- to 5-year-old children can make a hook having seen a premade one and use it correctly in the context of the task (Whalley, Cutting, & Beck, 2017). They understand the correct tool required to solve the Hooks task, as they can successfully identify the correct tool from a given pair (Beck et al, 2011). 4- to 5- year-olds will also readily copy adults when they demonstrate how to make a pipecleaner hook (Beck et al, 2011). However, children show difficulties in generating and/or demonstrating the correct solution in the context of the task. Children's suboptimal performance on the Hooks task, when they are required to solve the task without any prior experience or demonstrations, is especially interesting to developmental psychologists. In Experiment 4, I look at whether children at the youngest end of the testing age range for the Hooks task, 4- and 5- year-olds, are in fact capable of generating the solution, without being given any clues about the correct solution to the task. In this experiment, some children were asked to instruct an adult to solve the Hooks task, rather than physically solve the task for themselves.

3.1.1 Ill-structured problem solving

Ill-structured problems, in contrast to well-structured problems, lack information about either the start or goal states or the steps required to transform from one state to another (Reitman, 1965). Therefore, the problem requires that the participant provides their own information to fill these gaps. The Hooks task is one example of an ill-structured problem. Children are provided with information about the start and goal states of the problem, however they are not given information about how to transfer from one state to the other. The starting conditions are clearly defined, the necessary materials are provided and the objective of the task, to retrieve the bucket from the tube, is explicit. However, information regarding how to transform from the start to the goal state is missing. One possibility is that children find tool-innovation problems, like the Hooks task, difficult due to their ill-structured nature (Cutting et al, 2011; Chappell et al, 2013).

Ill-structured problem solving is associated with areas of the medial prefrontal cortex, known to undergo maturation throughout childhood and adolescence (Dumontheil, Burgess, & Blakemore, 2008). This complements the finding that tool-innovation abilities also improve throughout childhood (e.g. Beck et al, 2011). Further support for the ill-structured problem-solving account come from studies that have included manipulations of the Hooks task that make the problem more ‘well-structured’. For example, providing children with a demonstration of the solution required to transform from goal to end state, via a hook manufacturing demonstration, makes solving the Hooks task easy (e.g. Beck et al, 2011;

Cutting et al, 2011). This makes the problem more ‘well-structured’ by removing the need for children to innovate the solution for themselves.

It is likely that children’s difficulty with the Hooks task lies in the transformation from goal to end-state. In Experiment 4, I wanted to see whether I could make this transition easier, without having to give them any information about the solution and thus making it a ‘well-structured’ problem. Crucially, I wanted to see if young children can innovate the solution to the Hooks task for themselves, with as little information about how to do so as possible.

3.1.2 Children’s Private Speech / Verbalisations

People often talk aloud whilst they attempt to solve everyday problems, from indecipherable mutterings to more coherent explanations of their actions. Private speech (also referred to as self-talk) refers to the phenomenon whereby children talk to themselves or provide a commentary whilst completing a given task. It typically emerges with expressive language skills at age 2-3 years and is regularly observed between the ages of 3 and 8 years. Such overt private speech declines linearly with age across childhood, as it is gradually replaced by internalised, covert private speech (Winsler & Naglieri, 2003; Winsler, De Leon, Wallace, Carlton & Willson-Quayle, 2003). In his theory, Vygotsky (1978) posited that private speech served a function in the self-regulation of children’s cognition and behaviour. This adaptive theory of private speech is supported by studies with children, which shows that private speech increases with task difficulty (Duncan & Pratt, 1997; Fernyhough & Fradley, 2005).

Children’s private speech also appears to be implicated beyond the realms of self-regulation of cognition and behaviour. Private speech is related to children’s creativity (White & Daugherty, 2009). In their study, 3- to 5- year-old children’s creativity was assessed with Torrance's Thinking Creatively In Action and Movement (TCAM) test (Torrance, 1966). Their private speech was assessed separately, whilst completing problem-solving activities. Children who were rated as more creative (fluency and originality) engaged in more coping, reinforcing and problem-solving private speech than those with lower creativity scores. Those with above-average creativity scores, showed significantly higher levels of private speech which was directly relevant to task orientation and completion.

Private speech has also been related to problem solving performance. Fernyhough & Fradley (2005) measured 5- and 6- year olds' private speech and task performance whilst completing a version of the Tower of London (ToL) task. Incidences of private speech peaked when task difficulty was intermediate, i.e. not trivially easy for children nor too difficult. Most interestingly, children who produced more private speech performed better on the ToL task (they solved the task more quickly and did so in fewer moves). It is possible that private speech production is facilitative of problem-solving processes.

As well as correlations observed between spontaneous production of overt private speech and task performance, there is also evidence that encouraging participants to produce verbalisations can improve task performance. For example, the effect of verbalisation on performance during multi-step problems, such as the disk-transfer problem, has been examined in several studies. Participants who were asked to give reasons for their moves whilst completing the problems performed better (they required less moves to reach the solution) than those who completed the tasks silently (Ahlum-Heath & Di Vetsa, 1986; Berardi-Coletta, Buyer, Dominowski & Rellinger, 1995**).**

Children's production of explanations has also been linked to improved scientific reasoning and causal learning (Legare, 2014). In one study, 3- to 6-year-old children were shown a novel mechanical toy with interlocking gears. Half of the children were prompted to explain how the toy worked, whilst the other half of the cohort were not asked to give explanations (Legare & Lombrozo, 2014). The mechanical toy was then taken away, out of view of the child, and one of the gears was removed. The toy was then replaced on the table in front of the child, no longer working. Children were required to choose the missing part from an array of parts, in order to make the toy work again. Children who belonged to the group who had produced explanations of how the toy worked at the beginning, outperformed those who were not required to make such explanations. The authors concluded that producing explanations drew children's attention to the causal mechanisms of the task, and that overall producing explanations improves causal learning and promotes generalisation. Therefore, as well as drawing children's attention to the important causal properties of the task, producing explanations might also help children to generalise their knowledge and transfer it to problem scenarios.

Different types of verbalisations which are produced during a given task, also differ in their potential to affect task performance. For example, children who were asked to produce metacognitive, process-focussed verbalisations about their problem-solving on the Tower of Hanoi (ToH) task, outperformed those who were asked to simply think-out loud or remain silent (Berardi-Colleta et al, 1995). According to existing research, higher level verbalisations suggest the most substantial benefit to task performance (Ericsson & Simon, 1980; Ericsson & Simon, 1993). Higher level verbalisations involve participants making inferences, attention switching, and updating the contents of their working memory.

3.1.3. Verbalising and Tool Innovation

Chapter 2 demonstrated that prior experience using a premade hook in the task context made children significantly more likely to make a hook for themselves on subsequent attempts at the Hooks task. Using the distinction made by Beck et al (2014), children were capable of innovating the means to solve the task when they no longer had to innovate the solution to the task for themselves also. However, it remains unclear whether young children can generate the solution to the Hooks task for themselves i.e. can they bring to mind, without any prior demonstrations, that they need to make a hook to solve the task?

At present, the effect that verbalising during the Hooks task might have on children's likelihood to succeed is unknown. During all previous versions of the Hooks task (e.g. Beck et al, 2011; Cutting et al, 2011; Nielsen, Tomaselli, Mushin, & Whiten, 2014) children's verbalisations were not measured nor manipulated. Previously, children have not been explicitly encouraged or discouraged from talking whilst they attempted to solve the task. Children are merely given the task instructions and allowed to attempt the task, with neutral prompts to continue if a child fails to initiate contact with the materials or apparatus. In Experiment 4, I was interested to see whether children who were encouraged to verbalise how to solve the Hooks task, were more likely to be successful than those who were not.

In Experiment 4, I wanted to see if young children can generate the solution to the Hooks task, by bringing to mind, without any prior experience or hints, that a hook is required to solve the problem. Previous findings have suggested that it might be this aspect of the task, that children find especially difficult. Therefore, I wanted to promote children's chances of producing the solution, by encouraging children to verbalise their problem solving. In order to do this, I asked children to direct an apparently naïve adult to solve the Hooks task, rather than asking children to make a tool themselves. Children were required to innovate the solution to the task for themselves (I/we need to make a hook to retrieve the bucket), and then direct an adult to innovate the means to solve the task (how/where to bend the pipecleaner to make a functional hook).

In consideration of the ill structured problem account for children's poor performance (Cutting et al, 2011), I was interested in how children at the lower end of the testing age-range might be able to show success on the Hooks task, without directly being given any additional information to help them to solve the task. I made two crucial adjustments to the standard procedure used in the Hooks task. First, I reduced one of the physical demands of the task. Children were no longer required to make a hook themselves, by physically shaping a pipecleaner into a hook. Rather, they were asked to instruct an adult to solve the task. In doing so, second, children were required to make verbalisations about how to solve the task, in order to tell an adult what they needed to do to solve the problem. I chose this task manipulation, rather than asking children to explain their own attempts at the task, as I felt this was more likely to result in children producing higher-level verbalisations (see Ericsson & Simon, 1980, 1993). Otherwise, children might produce commentaries and verbalisations irrelevant to the task, while engrossed in the physical aspect of the task. Verbalisations which are relevant to completing a given task have been linked with better performance on other creativity tasks (White & Daugherty, 2009) and problem-solving tasks (Berardi-Colleta et al, 1995). Therefore, I felt it was important to give children the best chance of producing these higher-level verbalisations in a tool innovation context.

Importantly, neither of the procedural changes made the Hooks task a more 'well-structured' problem. Children who were asked to direct an adult to solve the task were not given any explicit prompts or clues about how to arrive at the solution. Therefore, this experiment can also provide insight into whether children's previously poor performance on the Hooks task can be explained by the ill-structured nature of the problem, or if there might be alternative explanations.

If being encouraged to produce high-level verbalisations facilitates innovative problem-solving, children who are required to direct an adult to solve task, will be more likely to generate a solution to the Hooks task by instructing the adult to make pipecleaner hook. If being prompted to make verbalisations does not facilitate innovative problem-solving, I would expect children to be no more likely to come up with the solution to the task in the condition which requires them to instruct an adult.

Secondly, if children's difficulty with the Hooks task is solely due to its ill-structured nature, instructing an adult to solve the task should not make children any more likely to produce the solution than if they must physically solve the task for themselves. If children in the instructing condition generate the solution to the Hooks task more frequently than those in the baseline group, this could suggest that children's difficulties are not necessarily caused by its ill-structure.

3.2 Pilot Study

I first present a pilot study, conducted at a science museum in Birmingham. The primary aim of this preliminary study was to evaluate the task procedure. I wanted to see if children in the target age range (4- to 5- year olds) were comfortable to engage in instructing an adult on how to solve the task. In addition, I wanted to check that our procedure for coding data live was effective, since I had the opportunity to collect a larger sample in a school setting later, where I was unable to video record children completing the task.

3.2.1 Method

3.2.1.1 Participants

The participants were 9 children (5 boys), aged 4- to 5- years, mean age 4 years 10 months (4; 10), (range = 4; 3 to 5; 11). The ethnic composition of the sample was 100% Caucasian. Children were recruited to the study via prior sign up. Parents responded to adverts placed via the University of Birmingham's Cognitive Development social media pages.

3.2.1.2 Materials

A new, sturdier version of the Hooks apparatus was used in this experiment (see Fig. 4). Using the old apparatus, there were a number of occasions when children were able to use a straight pipecleaner to drag the bucket up the side of the tube and retrieve it, without needing to make a hook. The smoother surface of the new apparatus' tube and the slightly narrower width made this more difficult. The new apparatus was also heavier and sturdier which made it more durable for transporting and less likely that children would try to upturn it.

This included a heavier base, which made it less likely that children would attempt to tip over the apparatus. The apparatus comprised of a transparent plastic tube (30cm length; opening 4cm in diameter) attached to wooden base (55cm x 55cm). At the bottom of the tube there was a small aluminium bucket (2cm x 2cm) containing a sticker. The bucket had a wire handle which required a hook to retrieve it from the tube. A straight 30cm black pipecleaner was also presented next to the apparatus.

Fig. 4. *New version of Hooks task apparatus.*

3.2.1.3 Procedure

The study took place in a classroom at the Thinktank Science Museum, Birmingham, which had been partitioned so that the experiment took place in one part of the room, whilst parents could watch their children taking part via live video link, out of view of their child.

The experimenter (CW) and the child sat together on the floor with the apparatus placed centrally in front of them. A video camera was set up in front of the experimenter and child, in view of the child, although this was not explicitly brought to the attention of the children. The experimenter told children: “I’ve got a problem. Can you see the bucket with a sticker inside [pointed to bucket] I need to get the bucket out of the tube, but I’m not sure how to get it? I have this to help me [picked up pipecleaner] and I’m allowed to try anything. Do you think you can tell me what I need to do to get the bucket out? If we get it, you can keep the sticker.” Where a child did not initiate an instruction within 10 seconds, neutral prompts were given: “Have you got any ideas? What shall I do? Is there anything I could try?”. Neutral prompts were offered whenever a child failed to offer any instruction or engage for a period of 15 seconds or more. The experimenter carried out the instructions given by the child. If instructed by the child to “bend the pipecleaner”, the experimenter asked, “Can you show me where I should bend it?” If a child did not tell the Experimenter to insert the hook into the tube and use it to hook the bucket, they asked “What shall I do with it now?”. The child was also encouraged to specify which orientation the hook should be inserted into the tube (i.e. hook first or straight edge first) if this was not explicitly specified.

If children failed to instruct the adult how to solve the task after 2 minutes had passed, they were given the opportunity to solve the problem for themselves: “Would you like to have a go?” A new, straight pipecleaner was placed next to the apparatus. After 60 seconds, if a child had not solved the task themselves, they were encouraged to put down their materials and were shown a premade pipecleaner hook (end-state demonstration): “Look at this. Do you think you can get the bucket now?”. Children who still failed to make a hook of their own, were again encouraged to put down their materials: “Watch this”. The experimenter then showed children how to make a pipecleaner hook (action demonstration), by holding a pipecleaner out in front of them, horizontally at its centre, in one hand. With the other hand, they bent the end of the pipecleaner to make a functional hook. Children were then asked: “Do you think you can get the bucket now?”

I coded whether children: instructed the adult to bend the pipecleaner, indicated a bending position that made a functional hook and told the experimenter to insert the hooked pipecleaner into the tube in the correct orientation.

3.2.2 Results & Discussion

Table 4 shows the number of children who passed the task at various stages. Two thirds of children were able to successfully instruct the experimenter to bend the pipecleaner in an appropriate position to make a functional hook to retrieve the bucket. The remaining three children did not tell the adult how to solve the problem, make a hook of their own spontaneously, or make a hook after being shown a premade hook. However, they all made a hook following an action demonstration by the adult experimenter.

Although I coded whether children: told the adult to bend the pipecleaner, indicated a bending position that made a functional hook, told the experimenter to insert the hooked pipecleaner into the tube in the correct orientation; all children who were successful in Phase 1 completed each of these steps. Therefore, the data are collapsed into Phase 1.

Table 4. *Instructing an adult pilot study: Children's success at each phase.*

	Success			
N	Phase 1: Instructed adult to make a hook	Phase 2: Made their own hook spontaneously	Phase 3: Made hook after end-state demonstration	Phase 4: Made hook after action demonstration
9	6	0	0	3

Results from the pilot study showed that children as young as 4 and 5 years old can bring to mind the pipecleaner hook solution to the Hooks task independently. When asked to instruct an adult how to solve the task, most children in this small sample were willing and able to do so. Not only did they instruct the adult to bend the pipecleaner, they selected the appropriate position on the pipecleaner to make a hook of the right size which would be functional for use on the task. In addition, they went on to tell the experimenter to insert the hook into the tube, at the correct orientation, to retrieve the bucket.

These findings are in contrast with previous studies which highlight children's difficulties in solving the Hooks task for themselves. In Experiment 4, I sought to obtain a larger sample to investigate this preliminary finding. I also included a Control condition, to compare the performance of children on the Hooks task when they were asked to solve it independently, by making a tool for themselves, or by instructing an adult to make a tool.

3.3 Experiment 4

3.3.1 Method

3.3.1.1 Participants

The participants were thirty 4- to 5- year olds (14 boys), mean age 5 years 0 months (5; 0), (range = 4; 6 to 5; 5). Children were recruited from a mainstream primary school in Warwickshire, UK. The ethnic composition of the sample was not recorded.

3.3.1.2 Procedure

Children were tested individually, in a quiet area outside their classroom, by one female experimenter, with another female researcher observing close by, but not actively participating in the experiment.

Children were allocated alternately by their class list and assigned to one of two conditions: Instructing or Control. In both conditions, the child and the experimenter sat at a table, with the test apparatus placed in front of them. In the Instructing condition, the experimenter said to the child: “I’ve got a problem. Can you see the bucket with a sticker inside [experimenter pointed]? I need to get the bucket out of the tube, but I’m not sure how to get it? I have this to help me [experimenter picked up pipecleaner] and I’m allowed to try anything. Do you think you can tell me what I need to do to get the bucket out? If we get it, you can keep the sticker.” Children were given 2 minutes to help the adult to solve the task. If children failed to tell the adult how to solve the task, they were then given two minutes to attempt to solve the task for themselves, with the following instruction: “Would you like to have a go and see if you can get the bucket out of the tube yourself? You can use this to help you [point to pipecleaner] and you can try anything you like.”

In the Control condition, children attempted the Hooks task independently. The experimenter said to the child: “Can you see the bucket with a sticker inside [experimenter pointed]? If you can get the bucket out of the tube, you can keep the sticker. Here is something you can use to help you [point to pipecleaner] and you can try anything you like.” Children were given 2 minutes to solve the problem and retrieve the bucket.

In both conditions, if children had failed to solve the Hooks task, they were given a further opportunity to solve the task, following an end-state demonstration from the Experimenter. For those children who were still unable to make a hook of their own, they were given an action demonstration by the Experimenter and allowed a final attempt to solve the task. Only one child failed to make a hook following an action demonstration. This child was given a premade hook to retrieve the bucket from the tube and win the sticker.

3.3.1.3 Coding

Data was collected by two experimenters, via observation. In addition to the active experimenter, a second live coder was present for 100% of trials. During Phase 1 of the Instructing condition, the experimenter and second coder both observed whether children: instructed the adult to bend the pipecleaner, indicated a bending position that made a functional hook and told the experimenter to insert the hooked pipecleaner into the tube in the correct orientation. During Phase 2, when children were asked to solve the Hooks task for themselves, observers recorded whether children made a hook, retrieved the bucket from the tube and the number of times the child modified the tool in some way e.g. bent it, straightened it, adjusted hook size. In Phases 3 and 4, following end-state and action demonstrations, it was recorded whether children 1) made a hook and 2) retrieved the bucket. Inter-observer agreement was 100%.

Success was defined as instructing an adult to make a hook (bend the pipecleaner in the appropriate place) for children in the Instructing condition. Success was defined as making a hook in the Control condition, regardless of whether children were successful at retrieving the bucket. This was to ensure that I did not underestimate performance in the Control group, since I was most interested in whether children can generate the correct solution to the Hooks task. In the Instructing condition, the hook was made by the adult and in the Control condition the hook was made by the child. In both instances, the child was required to bring to mind the solution for themselves. Across both conditions, a functional hook being made was the indicator of success, irrespective of whether the bucket was retrieved from the tube.

3.3.2 Results

There was no difference in success on the Hooks task based on gender in the Control condition. Statistics were not performed on these results as all participants were unsuccessful before the end-state demonstration. There was no difference in success on the Hooks task based on gender in the Instructing condition, Fisher's Exact Test, $p > .999$. Therefore, all data were combined for the subsequent analyses.

Table 5 shows success at each stage, defined as instructing the adult to make a hook/ making a hook independently. All children who instructed an adult to make a hook, also instructed them to insert the hook into the tube in the correct orientation. Only one child was unable to make a hook following an action demonstration and was given a premade pipecleaner hook to succeed on the task.

Table 5. *Experiment 4: Children's success on the Hooks task at each stage.*

		Success				
Condition	N	Phase 1: Instructed adult to make a hook	Phase 2: Made their own hook spontaneously	Phase 3: Made hook after end-state demonstration	Phase 4: Made hook after action demonstration	Unable to make a functional hook after Phase 4
Instructing	15	6	0	4	5	0
Control	15	N/A	0	10	4	1

Our original research question was whether children as young as 4 and 5 years can generate the solution to the Hooks task, without being given any information or experience of the solution within the task context. I was also interested if instructing an adult to solve the Hooks task would increase children's likelihood of generating the solution, or not, compared to when they needed to make a tool for themselves. Therefore, I compared the performance of children in the Instructing and Control condition by comparing how many children generated the solution to the Hooks task by the end of Phase 2, before any end-state or action demonstrations of the solution were provided by the experimenter. Children were significantly more likely to generate the solution to the Hooks task in the Instructing condition, compared with the Control condition, Fisher's Exact Test, $p = .017$.

As demonstrated in Table 5, no child was successful at making a hook prior to an end-state demonstration in the Control group. However, most children were able to innovate a hook following an end-state demonstration and all but one of the remaining children made a hook following an action demonstration. These findings provide further evidence that the Hooks task, remains a difficult problem for children to solve independently. In the Instructing condition, 6/15 children were able to generate the solution to the Hooks task, by successfully instructing an adult to make a hook. Although this means that the majority of children in the Instructing condition still did not generate the solution to the task, in light of previous findings with children of this age, these findings suggest that some children are able to bring to mind the solution to the Hooks task for themselves from a young age.

3.4 General Discussion

The main aim of the current study was to explore whether 4- to 5- year-olds can generate the solution to the Hooks task for themselves, and whether this was easier when they were required give an adult instructions on how to solve the task, rather than physically solve the task themselves. I found that children were more likely to show that they could innovate the solution when they were asked to instruct an adult, rather than having to make it for themselves. Indeed, no child showed that they could successfully solve the Hooks task by bringing to mind the solution and making it for themselves in the Control condition. In contrast, a significant number (40%) of children in the Experimental group, demonstrated that they could generate the solution to the Hooks task by instructing an adult on how to make a pipecleaner hook.

Firstly, it is unlikely that children in the Control condition failed to demonstrate the solution to the task because they lack the necessary dexterity or tool-making ability to make a pipecleaner hook. Observations of the number of tool modifications children made showed that children in the Control condition rarely made any modifications to their pipecleaners at all. Therefore, it was not the case that children were making tools or modifications to their pipecleaners that were not deemed to be functional. Rather, they made no attempts to modify the pipecleaner at all. In addition, most children in the Control condition could successfully make a hook following an end-state demonstration, without an action-demonstration. This shows that they knew how to transform the straight pipecleaner into a hook, suggesting that they have both the appropriate knowledge of tool-making and the necessary dexterity to coordinate making a hook.

Successful children in the Instructing condition were able to instruct an adult to bend the pipecleaner into a hook, in the correct position to make it functional for retrieving the bucket. This shows an understanding not only of the required end-state tool, but also the physical transformation required to turn the straight pipecleaner into a hook. Previous studies of children in this age category have shown that they rarely solve the Hooks task without a demonstration of what the required tool looks like and/or how to make it (e.g. Beck et al, 2011; Cutting et al, 2011; Nielsen et al, 2014). Cutting and colleagues (2011) proposed that it is the ill-structured nature of the Hooks task which makes it problematic for young children and specifically, the lack of information on how to transform from the start to the goal state. The results from Experiment 4 show that some younger children can come up with the solution to the Hooks task independently. No information regarding the transformation from goal to end state was given to the children in either condition. If poor innovation on the Hooks task is solely driven by its ill-structure, I would have expected to observe children to be equally likely to generate the solution in both conditions.

Given that no further information was given to children in the Instructing condition about how to solve the task, I suggest that asking children to verbalise the solution, by instructing an adult, facilitated their subsequent innovation. As previously discussed, research has linked encouraging participants to verbalise their solutions, to improved problem-solving performance (Ahlum-Heath & Di Vetsa, 1986; Berardi-Coletta et al, 1995). Since the effect of verbalisation on tool innovation is not yet understood, the reasons why verbalisation could improve tool innovation performance are uncertain. Berardi-Colleta et al (1995) argued that verbalisation is not in itself responsible for improved task performance, rather the processes which take place as a result of producing explanations of problem-solving behaviour. Undergraduates who were required to make metacognitive, process-focussed verbalisations showed superior ToH performance compared to those who were asked to produce problem-focused or think-aloud verbalisations and silent controls. Berardi-Colleta and colleagues (1995) argue that encouraging process-focussed, metacognitive verbalisations causes participants to shift their focus to process-level information. In turn, they can solve more complex problems and do so more efficiently.

It is possible that the Instructing condition encouraged a similar shift in children's focus of attention to process-level information. This could explain why children in this condition outperformed those in the Control condition. However, unlike Berardi-Colleta and colleagues (1995), I did not provide specific prompts, via questioning, to shift their attention to process-level information. Had I done so, for example by asking children to tell us in advance how they planned to solve the task and why they thought this was a good idea, I might have observed even greater levels of success in the Instructing condition. Future research can expand these findings to explore whether explicitly encouraging metacognitive verbalisations can improve tool innovation.

As well as children having to verbalise their problem-solving in the Instructing condition, they also received a different social experience compared with children in the Control condition. Children might have found their role as the instructor in this condition to be motivating because it created a sense of helping which led to better innovation of the solution to the task. Prosocial, helping type behaviours emerge early in childhood. Warneken and Tomasello (2006) found that 18-month infants display altruistic, helping behaviours. They found that young children show a natural tendency to help other people to solve problems, even when the other person is unfamiliar to them and there is no obvious benefit or reward to the child for helping. Similarly, naturalistic observations of children aged from 2-

to 3- years have shown that they spontaneously assist their parents going about their household chores, without prompting or instruction (Rheingold, 1982). As well as the personal reward for solving the task (a sticker), the process of needing to help the adult to solve the task may have been especially motivating for children and facilitated their innovation of the task solution. In contrast, the presence of the adult in the Control condition, who was not playing an active role in solving the task by either helping them or needing the child's help, may have produced the opposite effect.

Children who were instructing an adult are also likely to have engaged in more social interaction than children in the Control condition, which may have improved their performance. Indeed, young children are excellent social learners (Carr, Kendal, & Flynn, 2015) and are motivated to learn socially. Most 3- to 5-year olds show strong preferences to learn socially rather than asocially, when given a choice between using social information to solve a task or attempt the task individually (Flynn, Turner, & Giraldeau, 2016). Although the current study did not give children the opportunity to learn socially via observation from the adult, the adults' presence and engagement on the task in the Instructing condition may have allowed children to learn about aspects of the task by providing them with visual feedback whilst they watched them carry out their instructions. This social aspect of the task may have facilitated the problem-solving process.

Not all children prefer to learn and solve problems socially. Some 5-year-olds show a preference to learn asocially and are able to solve tasks this way, when this strategy matches their preference (Flynn et al, 2016). Individual differences in children's social preferences for problem solving could explain why some children found the Instructing condition beneficial, whilst others did not. The role of social context and children's social preferences on tool innovation should be explored further to investigate whether when the social context of the study is more compatible with their social learning preferences, innovation is facilitated.

Exploring how different social contexts and individual preferences for social learning might affect tool innovation could have far reaching consequences for understanding how we can maximise children's chances of success on innovation tasks.

Further investigation is required to understand what contributed to the improved tool innovation performance observed in this study. In order to unpick this finding, it is necessary to compare children's generation of the solution when they are asked to produce explanations whilst completing the task for themselves compared with explaining to an adult how they should solve the task. If vocalising the solution to the problem, and perhaps the meta-cognitive processes which this invokes, is facilitative for innovative performance, one might expect children to perform equally well whether they are telling an adult how to solve the task or explaining their own attempts to solve the task. If this were not the case, and instructing an adult were more beneficial to innovation of the solution, we might consider that the increased opportunity for social interaction or the motivational effect of helping were responsible for improving performance.

Finally, it is also possible that some children who do not show success on the standard version of Hooks task are able to generate the solution but fail to display it in this task context. It is possible that by asking children to direct an adult to solve the task and therefore taking away one of the physical demands of the task, children had more mental capacity available to bring to mind the solution. A follow-up study to determine whether or not children are more likely to generate the solution to the task when they are not also required to carry out the physical demands, would be to ask children to describe how they would solve the task, without having them physically attempt the task.

In summary, in Experiment 4, I found that children were more likely to demonstrate that they could generate the solution to the Hooks task when they were asked to instruct an adult to solve the task, rather than physically solve the task for themselves. However, whilst instructing an adult boosted performance, innovation of the solution to the Hooks task remained a difficult problem for most 4- to 5- year-olds in this sample. In line with previous studies, children in the Control condition who were required to solve the task for themselves performed poorly, with no child succeeding at innovating a hook prior to end-state and action demonstrations. Whilst being required to direct an adult Experiment 4 made some children more likely to produce the solution to the Hooks task, it did not make the problem trivially easy; the majority still failed to innovate the solution. The results do suggest, though, that previous versions of the Hooks task may have led us to underestimate their potential to generate solutions to tool innovation problems. Moreover, they demonstrate that children's innovation can be facilitated without having to give them clues or information about the solution. Later in this thesis I will explore other ways in which we might be able to promote children's tool innovation and support children not only to generate the solution to the hooks task for themselves, but also to generate the means to solve the task for themselves. It is hoped that by exploring how tool innovation can be facilitated, we can also help to piece together the puzzle of what makes innovation problems difficult for children.

Chapter 4

Is children's tool innovation related to their divergent thinking ability?

The experiment in this chapter is published as part of a paper here[2]:

Beck, S.R., Williams, C., Cutting, N., Apperly, I. A., & Chappell, J. (2016) Individual differences in children's innovative problem-solving are not predicted by divergent thinking or executive functions. *Philosophical Transactions of the Royal Society B,* 371.

[2] The study in this chapter (Expt. 5) appears in the above referenced paper (Beck et al, 2016) as Study 1. I took the lead role in coming up with the original idea, design, data collection and analysis of Experiment. I also contributed to the interpretation and write up. I have re-written the study to form Chapter 4 of this thesis.

4.0 Introduction

Human capacity for creativity and generating new ideas has been critical for our cultural and technological progress. To understand what makes a good innovator is to understand a piece of cognition that has been fundamental to our success as a species. At present, little is known about the processes underlying tool innovation, and whether innovation represents a domain general process or a group of domain specific processes. One way in which we can explore this question is by examining whether performance on tool innovation tasks, such as the Hooks task, is related to performance on other measures which might tap similar cognitive processes. In doing this, we might begin to build a picture of what makes a good innovator and if these individuals within a population can be identified by a predictable repertoire of skills and abilities.

In numerous domains, differences in children's personal characteristics have been related to their abilities. For example, Van der Graaf, Segers and Verhoeven (2018) found that kindergarten children's response inhibition and verbal working memory is predictive of their ability to evaluate scientific evidence and their experimental behaviour. Fusaro and Smith (2018) observed a positive correlation between 4- to 6- year-olds' inquisitiveness, as measured by the number of questions asked about a picture of a novel object with unusual characteristics, and their performance on a picture problem solving task. On a task requiring children to resist the temptation to cheat, by peeking at the identity of a toy when the experimenter was out of sight, O'Connor and Evans (2019) found that children with increased Theory of Mind and parent-reported social skills were significantly less likely to cheat. Alloway, McCallum, Alloway & Hoicka (2015) also found that 6- to 7- year-olds with better verbal working-memory were also better liars on a temptation resistance paradigm.

To date, little is known about how individual differences in children's personal characteristics might relate to their tool innovation ability. In one study, which is written up in a paper with the study included in this chapter, Beck, Williams, Cutting, Apperly & Chappell (2016) investigated individual differences in executive functions (EF), including inhibition, task-switching and working memory, and performance on the Hooks task. No single measure of EF was predictive of Hooks task success, suggesting that none of these processes are identified as the crucial limiting factor in children's tool innovation difficulties. Children's receptive vocabulary, measured by the BPVS, was predictive of Hooks task success. It could be the case that those children with stronger language comprehension are better able to understand and interpret the task instructions and so are more successful on the task. However, this seems unlikely given the relatively simple and clear instructions given in the Hooks task. Perhaps a more likely explanation is that the BPVS in this study could represent general intelligence, as has been previously argued (Beck, Riggs, & Gorniak, 2009), and that it is general intelligence that might predict Hooks task performance.

Most standard definitions of creativity used today are based on that of Stein (1953), who defined creative work as something which is both novel and useful or satisfying. Within the creativity literature, it is widely accepted that for something to be creative it must be original and effective (see Runco & Jaeger, 2012 for a review). Creative problem solving, differs from other types of problem solving, in that it requires the production of a novel problem solution (Mumford, Mobley, Reiter-Palmon, Uhlman & Doares, 1991), rather than relying on previously acquired solutions. It follows that the Hooks task requires creative problem solving, since it is necessary to generate a novel problem solution, by transforming the available materials into an appropriate tool and using it to retrieve the bucket. To go one step further, we might predict that more creative individuals are more likely to succeed on tool innovation measures such as the Hooks task.

Divergent thinking describes the thinking process which involves generating multiple ideas and solutions. This is in contrast to convergent thinking, whereby a single correct solution is focused upon (Guilford 1956; Runco, 1999). Wallach (1976) made a distinction between divergent thinking and creativity. It is fair to say that although divergent thinking is not synonymous with creativity, creative thinking involves divergent thinking. Milgram and Milgram (1976) evidenced the theory that divergent thinking is a necessary component of creative thinking: more unusual responses emerged when a larger quantity of ideas was produced. Divergent thinking tests are excellent predictors of creative potential (Wallach & Wing, 1969). The relationship between divergent thinking and creativity might best be defined as this: performance on divergent thinking tasks is an indicator of creativity and of an individual's potential for creative problem solving (Runco & Acar, 2012). In order to solve the Hooks task, children are required to think creatively and flexibly about the materials available to them and how to transform these into a solution. Therefore, it is possible that individuals who think divergently and generate multiple ideas are more likely to come up with the solution the Hooks task. This forms the basis of the study which follows, which uses measures of divergent thinking as a way of capturing an individual's creative potential.

Fluency tasks are one way to measure an individuals' creativity and divergent thinking. For example, during verbal fluency tasks such as the FAS, participants are required to produce as many words as possible, beginning with a given stimulus letter, within a specified time (Bolla, Lindgren, Bonaccorsy & Bleecker, 2006). In his structure of intellect model, Guilford (1956) implicated fluency, flexibility and originality in divergent thinking. Similarly, Torrance (1965) believed that those capable of producing lots of ideas during fluency tasks were more likely to think creatively than those who produce fewer ideas. Therefore, fluency tasks were used as our measures of divergent thinking in this study. I hypothesised that individuals who scored highly on measures of divergent thinking, and thus generate larger numbers of ideas and solutions, would also be more likely to perform well on two tool innovation tasks.

4.1. Experiment 5

The present study aimed to look at the performance of individuals across a battery of tasks requiring innovative and divergent thinking. First, children completed a task, designed to capture creativity and fluency, whereby they had to draw as many pictures from blank circles as possible within 2 minutes. This was similar to a measure in the Torrance Tests of Creative Thinking (Torrance, 1966) which has been widely used to investigate children's creativity. Second, they attempted the Hooks task. Third, children completed the Object Uses Task, which was a shorter version of the functional fluency task designed by Defeyter et al (2007). They describe the task as a variant of verbal fluency and test of divergent thinking. Here children were required to come up with as many different uses of a given object as possible. Finally, children completed the Floating Ball Task, as a measure of tool innovation and creative problem-solving. This was a version of the floating peanut task which was originally adapted for use with children by Hanus et al (2011). Children received the tasks in a fixed order, so that they received as close to the same experience as possible. The overall aim was to identify potential correlations between measures in order to understand whether children who show good performance on tool innovation tasks, also demonstrate greater levels of creative, fluent and flexible thinking. I hypothesised that those children who scored more highly on measures of fluency would also be more likely to succeed on the tool innovation tasks.

4.1.2 Method

4.1.2.1 Participants

The participants were 40 children (20 boys) aged 5- to 7- years, mean age 6 years and 5 months (6;5) (range 5;5 - 7;4) from one mainstream primary school in the West Midlands, UK. One further child was tested but excluded from analysis, as they had overseen another child completing the Hooks task.

4.1.2.2 Procedure

Children were tested individually, in a quiet space outside of their school classroom. Children were seated next to a female experimenter (CW) who live coded the experiment. A second coder was present throughout. Children completed a short battery of tasks in a fixed order: Circles Task, Hooks Task, Object Uses Task, Floating Ball Task.

4.1.2.2.1 Circles Task

Children were presented with an A4 piece of paper with a series of blank circles on it and a pencil. Two of the circles at the top of the page had already been used to draw a pig and a clock. Children were told *"See these circles [points]. You can use them to make different drawings."* Their attention was then directed to the pre-drawn pictures and they were asked *"Can you make as many different drawings as you can?"* Children were given two minutes to complete the task and at each new circle, once a child began drawing, they were asked *"What is this picture going to be?"* so that this could be noted by the experimenter. Neutral prompts were given by the experimenter where a child ceased to draw for ten seconds or more e.g. *"Can you do any more drawings?"* After two minutes, children were praised and given a sticker and progressed to the next task.

4.1.2.2.2 Hooks Task

Children first completed a pipecleaner bending exercise, to highlight the physical properties of the material. The experimenter encouraged children to *"Watch this"* whilst they wrapped a pipecleaner around a pen and removed the pen to demonstrate that the pipecleaner holds its shape. Children were then given a pipecleaner and a pencil of their own and encouraged to try for themselves. Where a child struggled to do this independently, the experimenter helped ensure that all children managed to wrap a pipecleaner around a pencil before attempting the task. The test apparatus was then placed in front of the child. This comprised of a transparent plastic tube (22cm length; opening 5cm in diameter) attached to a cardboard base (see Fig. 5). At the bottom of the tube there was a small bucket containing a sticker. The bucket had a wire handle which required a hook in order to retrieve it from the tube. In the innovation phase, the experimenter told the child *"If you can get the sticker out of the tube then you can keep it. Here is something that can help you"* and a straight, 30cm pipecleaner was placed in front of the child, next to the apparatus. Children were given one minute to try to retrieve the sticker, with neutral prompts provided by the experimenter if they hesitated or failed to attempt retrieval. If a child did not make a hook, they completed a manufacture phase. The child was encouraged to put down their materials and watch the experimenter, who took out their own pipecleaner and held it out in front of them in clear view of the child. With one hand holding the middle of the pipecleaner horizontally, the other hand was used to bend one end of the pipecleaner to make a hook. The experimenter then removed their pipecleaner hook from sight and asked the child "can you get the sticker out". No child failed to make a hook following this adult demonstration.

Fig. 5. *Hooks task apparatus and materials used in Experiment 5.*

4.1.2.2.3 Object Uses Task

Children completed an object uses task taken from Defeyter et al (2007). Two pictures of familiar objects, a brick and a blanket, were laminated on white card each measuring 21cm long x 15cm high (see Fig. 6). Children were presented with the two fluency tasks in a fixed order: brick first, blanket second. On each trial, children were shown the picture of the object, told its name and asked to generate as many different uses for the object as they could. The experimenter said "*See this brick /blanket (pointed to object). Think about the different things you can do with it. Tell me as many different things as you can."* Children were given a minute to come up with as many uses as possible for each object, after which time the picture was removed and they proceeded to the next trial. Children were praised and given a sticker for their efforts.

Fig. 6. *The 'familiar objects' used for the Object Uses task: a brick and a blanket.*

4.1.2.2.4 Floating Ball Task

Children completed a 'wet' version of the Floating Peanut Task from the original study of Mendes, Hanus and Call (2007) with orangutans and more recently adapted for use with children by Hanus et al (2011). Test materials were a transparent plastic tube (22cm length; opening 5cm in diameter) attached to a plastic board, within a shallow plastic tray (see Fig. 7). A small ball was floating in the tube which was already one quarter filled with water. A jug filled with water was positioned next to the apparatus in the tray. No other tools were available.

Children completed a warm-up phase, in order to familiarise themselves with the test situation. In the original version of the task by Hanus et al (2011), children poured water to water plants. In the current version of the task, children were asked to pour water from one transparent plastic jug containing water, into an empty transparent plastic jug up to a marked, solid black line. Once this was completed plastic jugs were removed and the test apparatus was placed in front of the child. The experimenter said to the child: *"Let's play a game. Look, there is a ball inside the tube. If you can get the ball out, you will win a sticker."* A trial lasted 3 minutes and the experimenter remained positioned next to the child throughout the trial. Children were given neutral prompts e.g. *"If you have an idea, just try it", "How might* *you get the ball out of the tube?"*. After 3 minutes, if a child had failed to retrieve the ball, the experimenter asked the child one last time: *"Would you like to try something else?"* They were given a further minute to attempt with their final strategy otherwise, the trial was ended. Children who failed to retrieve the ball were encouraged to pour the water to retrieve the ball and were given a sticker.

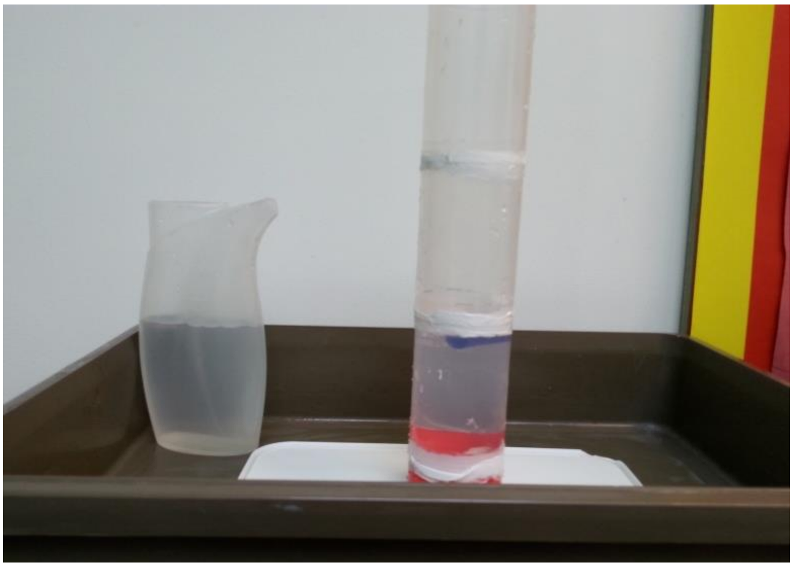

Fig. 7. *Floating ball task apparatus.*

4.1.2.3 Data Coding

4.1.2.3.1 Circles Task

Participants received a score for the total number of pictures they drew, excluding any repetitions. A repetition was determined on the basis of the label given to a picture by the child. For example, if a child drew two identical looking pictures of a face but labelled them "Me" and "Mommy" then a child would be given credit for both pictures and receive a score of 2. If a child drew two identical looking pictures of a face but labelled them "a face" and "a face" then this would be considered a repetition, they would only receive credit for one of the pictures and they would receive a score of 1. Agreement of total scores and repetitions between the two coders was 100%.

4.1.2.3.2 Hooks Task

It was recorded whether children made a hook and successfully retrieved the bucket and the time taken to pass the task. Latency to solve the task was measured live, with a stopwatch, and was defined as the point at which the bucket was lifted from the base of the tube. Agreement on successful hook innovation between the coders was 100%. Latency was only coded by the observer.

4.1.2.3.3 Object Uses Task

The experimenter and a blind coder coded all responses in terms of whether they were a 'design function', a 'novel function', or 'other suggestion'. Inter-coder agreement was 80% and disagreements were resolved by a third coder. A design function is a use of the object that is an extension of its original design. For example, using a brick to "build a house" is a design function. A novel function is a function of the object which is unrelated to its design whilst still plausible given the mechanical properties of the object e.g. size, shape. For example, using a brick "to prop open a door" is a novel function. Other suggestions included suggestions with no end goal e.g. "stand on it", "throw it". Comments which were merely descriptive and did not involve acting upon or using the object e.g. "It is heavy", "it is soft" were excluded from analysis. Participants were scored for the total number of 'design functions' and the total number of 'novel functions' they produced. They were also scored for their 'total object suggestions', which was calculated by adding together the design functions, novel functions and other suggestions they produced on both the brick and blanket trails.

4.1.2.3.4 Floating Ball Task

It was recorded whether a child inserted water into the tube apparatus and the latency from trial start to first water insertion was recorded. Children were also scored on a pass/fail basis, with success being defined as using the water to raise the level of the ball until it could be retrieved from the tube. The latency from trial start to the ball being retrieved from the tube was also recorded. Agreement between the two coders on which children passed and failed the task was 100%.

4.1.3 Results

4.1.3.1 Gender Differences

I looked for gender differences using *t*-tests on parametric measures (age, total circles, total object suggestions) and using a χ^2-test on the categorical variable of whether children successfully retrieved the bucket in the Hooks task. There were no significant effects (results closest to significance were total circles, $t(38) = 1.33$, $p = 0.191$ (boys $M = 3.85$, s.d. = 1.53; girls $M = 3.30$, s.d. = 1.03) and total object suggestions, t(38) = 1.33, $p = 0.191$ (boys $M = 10.70$, s.d. = 3.91; girls $M = 9.20$, s.d. = 3.17). Due to near ceiling performance on the Floating Ball Task, I did not look for gender differences.

4.1.3.2 Descriptive Statistics

Table 6 shows a brief summary of children's performance on the divergent thinking measures.

Table 6. *Experiment 5: Children's performance on the Divergent Thinking Tasks.*

Measure	Mean (s.d.)	Minimum Score	Maximum Score

Total Circles	3.57 (1.32)	1	7
Total Object Suggestions	9.95 (3.60)	3	23
Design Functions	4.55 (2.27)	0	10
Novel Functions	2.12 (1.87)	0	6

4.1.3.3 Circles Task

Children drew an average of 3.58 circle pictures (SD 1.32, range = 1-7).

4.1.3.4 Hooks Task

Success on the task was defined as making a hook and using it to retrieve the bucket from the tube. Nineteen children (47.5%) succeeded on the task and took on average 30.95 seconds (SD 17.97, range = 7-70). Two children made a hook on the test trial but failed to succeed in retrieving the bucket from the tube.

4.1.3.5 Object Uses Task

Children came up with an average of 9.95 total suggestions, which included design functions, novel functions and other suggestions, (SD = 3.59, range = 5-23).

I also looked at functional fixedness on this task to check my findings against those in the original task (Defeyter et al, 2007). Defeyter and colleagues (2007) found that younger (5 years) and older (7 years) children produced more design functions than anything else. Design functions are suggestions that are an extension of a known design function of the object e.g. you can build a wall with a brick. Younger children appeared to be less constrained by the design functions of objects and produced more novel uses for the objects than older children e.g. you can use a brick to prop open a door. In the current study, children suggested more design functions (M = 4.55) than novel functions (M = 2.12). An ANOVA with age (Younger/Older: spilt at 76 months, the school year group boundary) and Function (Design, Novel) showed a main effect of Function, $F(1, 38) = 23.71$, $p < .001$, partial $\eta 2 = 3.84$, but no main effect of ($p = .478$) nor interaction with age ($p = .388$).

4.1.3.6 Floating Ball Task

Success was defined as a child pouring water into the tube and retrieving the ball. Children performed near ceiling, with 37/40 children passing the task, although the time taken to pass the task was variable. Children took an average of 37.89 seconds to begin pouring water into the tube (standard deviation 53.67, range 1-177) and 62.70 seconds to retrieve the ball from the tube (standard deviation 54.84, range 8-208). As performance was near ceiling, this measure was excluded from any further analyses.

4.1.3.7 Individual Differences

A binary logistic regression was carried out to see whether success or failure on the Hooks task could be predicted by any of the following measures: Age (in months), gender, total number of different pictures drawn (circles task) and total suggestions score (object uses task). None of these measures was a significant predictor of performance on the Hooks task (Table 7) and the model appeared to be a poor fit to the data (Cox & Snell $R^2 = 0.117$). The model predicted 73% of those who failed the task, but 56% of those who passed. I found no evidence that children's tool innovation was related to their performance on either of our divergent thinking measures.

Table 7. *Experiment 5: Binary logistic regression predicting success on the Hooks task by performance on the Object Uses and Circles task.*

Predictor	B	s.e.	Wald	d.f.	*p*-value	odds ratio

Age	0.06	0.05	1.47	1	0.229	1.07
Gender	-0.81	0.70	1.37	1	0.243	0.44
Circles Fluency	-0.24	0.27	0.80	1	0.371	0.78
Object Uses Fluency	0.12	0.11	1.17	1	0.279	1.125

4.1.4 Discussion

Our divergent thinking measures did not predict success and failure on the Hooks task, meaning I found no evidence that children's tool innovation is related to their divergent thinking capabilities. This is somewhat surprising, given the demands of the task. I predicted that children who are better at producing multiple ideas would be more likely to come up with the hook tool solution. It is possible that the ability to generate multiple ideas and solutions is not a necessary, or sufficient, skill to succeed on the Hooks task.

To solve the task children are required to converge upon a single, correct solution; that is to bend the pipecleaner to create a hook, in order to retrieve their reward. Therefore, it could also be possible that children who are better at convergent thinking are better at solving innovative tool problems such as the Hooks task, where there is only one correct solution. To investigate this, children's performance on convergent thinking measures and their performance on the Hooks task could be compared, to see whether convergent thinking is predictive of innovation. The Picture Completion subtest of the Wechsler Primary and Preschool Scale of Intelligence (WPPSI-R) (Wechsler, 1989) and the Peabody Picture Vocabulary Test-Revised (Dunn & Dunn, 1981) have been used to measure children's convergent thinking (Lloyd & Howe, 2003). However, it is also important to consider that divergent and convergent thinking may not be useful constructs for thinking about tool-based problem solving, in terms of being predictive of children's innovative ability. It is probable that both types of thinking are implicated in reaching the solution to the task, but that neither of these abilities are sufficient to explain the individual differences we observe in young children’s performance.

An alternative possibility is that the measures used in this experiment were not optimal for capturing children’s full divergent thinking potential. Children were asked to produce as many ideas as possible, but their attention was not drawn to the fact that they would be timed or that there was a time limit to complete this task. This was a conscious decision by the experimenter not to put young children under unnecessary pressure, which could be both an unpleasant experience for the child and in turn negatively affect task performance. As such, future studies involving divergent tasks such as these might wish to draw children’s attention to the competitive nature of the task, in a subtle way. For example, “there’s no need to draw in too much detail, just draw as many different pictures as you can”.

It is worth noting children’s excellent performance on the Floating Ball task. These findings are in contrast with the those of Hanus et al (2011), who found that only half of 6-year-olds were successful on their ‘wet’ version of the Floating Peanut Task. There were some procedural differences between the versions of the task ran by Hanus et al (2011) and the version that was run in this study, which might explain the differences observed in children’s performance. Some elements of the original version might have made the task more difficult. Children completed a warm-up which involved watering plants with a jug of water, then left and re-entered the room a few minutes later, before attempting the task. After they had watered the plants, the jug was placed on the table, near the child but was not positioned immediately next to the apparatus. Hanus et al (2011) rejected the point that children’s poor performance could have been a result of the jug of water acquiring a ‘watering function’ via the warm-up task, since they assert that one exposure to watering plants would not be sufficient to induce functional fixedness of the function of the pitcher.

This cannot be ruled out, however more recent research suggests that innovation on this task remains low even after controlling for functional fixedness (Ebel et al, 2019).

It is possible that children did not consider the pitcher as an available solution because of its positioning not being close to the apparatus. In the current version of this task (Floating Ball Task), children poured water from one jug into another in their warm-up phase and did not exit the room before attempting the task. In addition, the apparatus and the solution (jug of water) were placed together in a tray. Initially this had been done to try and minimise the mess made from potential spillages, since the study took place in a school. However, providing the solution in a tray alongside the test apparatus may have provided a holistic cue to children and facilitated their performance. Ebel and colleagues (2019) found that children's performance on the Floating Peanut Task was improved when the pitcher of water was transparent vs opaque and was closer to the apparatus. Together, these differences in children's performance highlights their sensitivity to subtle differences in task pragmatics and structure.

Children always completed the Floating Ball Task last in this study, having completed another innovation task and two tasks requiring fluent and creative thinking. This prior experience may have placed children into a problem solving or creative thinking mindset, which made the generation of the solution to this problem easier. This is something that I will discuss in light of the findings in the next chapter.

It would be premature to conclude that divergent and creative thinking plays no part in children's tool innovation ability, especially when these abilities have only been compared with one other tool task (the Hooks task), since performance on our other tool measure (Floating Ball Task) was near ceiling. Rather than looking for differences between individuals' divergent thinking ability, it is possible that tool innovation might be related to individuals' ways of thinking. Those who engage in more creative thinking might be more likely to solve the Hooks task. In pursuit of supporting innovation, it could be worthwhile to explore whether priming creative ways of thinking can support innovation. Creative ability in children is not a fixed construct and has been shown to be improved significantly by training (Gu, Dijksterhuis & Ritter, 2019). Children who engaged with a two-hour creative thinking exercise were significantly better at subsequent creativity tasks measuring fluency and originality, than those who did not. In a similar way, can children benefit from the opportunity to engage in creative thinking and problem solving before attempting the Hooks task? These questions have important implications for educational settings and the possibility that innovation need not necessarily be an all or nothing ability, rather a skill that can be nurtured and developed. In the next chapter, I explore how priming abstract thinking, which facilitates creativity, affects children's subsequent tool innovation.

In summary, the current study found that divergent thinking ability fails to predict children's likelihood to solve tool innovation tasks. That is, the ability to generate multiple, novel ideas on measures of fluency and creativity does not appear to the limiting factor on successful tool innovation. This suggests that looking for individual differences in children's creative characteristics might not be the best way to explore the relationship between innovation and creativity. In the following chapter, priming abstract thinking, which has been shown to improve creative performance (Liberman et al, 2012), is investigated.

Chapter 5

Can spatial distance priming promote children's tool innovation?

5.0 Introduction

In Chapter 4, I found that children's tool innovation did not correlate with measures of their creativity, measured by divergent thinking. However, it remains possible that creative thinking is implicated in solving tool innovation tasks. Remembering solutions to previously encountered problems is insufficient to explain our ability to solve novel problems. When faced with a novel physical problem, it is likely that we apply creative thought (Liberman, Polack, Hameiri, & Blumenfeld, 2012).

In Chapter 4, I did not attempt to encourage or manipulate children's creative thinking. The current studies aimed to investigate whether encouraging abstract thinking improves children's ability to solve a novel tool problem. Previous literature has shown that encouraging abstract thinking, via spatial distance priming, significantly improved children's creative performance both in terms of fluency and originality (Liberman et al, 2012). I was interested to see if these findings extended to the Hooks task and thus tool-innovation.

5.1 Construal Level Theory

Although we are only able to directly experience the present reality, we are also capable of remembering our past, imagining our future, predicting events and speculating about alternative outcomes. Such predictions, imaginings and memories are mental constructions that are separate from our direct experience and as such are 'psychologically distant'. Construal level theory (CLT) defines psychological distance as "a subjective experience that something is close or far away from the self, here and now" (Trope & Liberman, 2010, p. 440). An object or experience might be psychologically distant from a person on several different dimensions, such as time, space, social distance or hypotheticality. An event is more psychologically distant the further it takes place in the past or future (temporally distant), the more distant the location in which is takes place (spatially distant) and when the event is increasingly unlikely to occur (distant in terms of hypotheticality).

CLT asserts that as psychological distance increases, construals become more abstract. Likewise, as the level of abstraction increases, the psychological distance that a person experiences also increases. It is thought that construal levels can broaden and narrow our mental horizon, allowing us to represent and experience things in an increasingly abstract or concrete way (Trope & Liberman, 2010). Individuals represent proximate events using more concrete (low-level) construals and distant events using more abstract (high-level) construals (Liberman & Trope, 1998). Empirical studies have demonstrated that psychological distancing encourages the use of abstract, higher-level mental construals. In one study, participants were asked to complete questionnaires which required them to imagine engaging in everyday activities, such as moving to a new house, spending a weekend with their family or watching television, either in the near future (tomorrow) or in the distant future (next year). Participants used higher-level descriptions more frequently in the distant future condition compared with the near future condition. For example, when asked to describe the act of "cleaning the house" in the distant future, it was more frequently described in terms of the overall goal e.g. "showing cleanliness", whilst in the near future, participants more often described the means of achieving the goal e.g. "vacuuming the floor" (Liberman & Trope, 1998). This suggests that when we represent distant future activities, we are more likely to use higher level mental construals than when we represent activities in the near future.

Abstract thinking, such as is implicated in higher-level construals, has been associated with enhanced creativity (Ward, 1995). This claim has been explored by Forster, Friedman and Liberman (2004), who investigated how temporal distancing affected participants' performance on insight problems and creativity tasks across several experiments. In one experiment, undergraduate participants were first required to do a priming task, where they had to imagine themselves doing various activities (e.g. reading a book) either in the near future (tomorrow) or distant future (one year later). Participants then completed three classic insight problems. Those who had imagined themselves and their lives in one year's time, rather than tomorrow, in the priming phase were better at solving subsequent insight problems. In a separate experiment, the effect of temporal distance on creative generation was also measured. Participants either had to come up with creative *ways* of greeting someone or give reasons *why* they might have to greet someone, either in the distant future or in the near future (e.g. "a year from now / tomorrow… I will greet someone because…"). Imagining themselves in the distant future improved creativity, only when they were required to generate reasons *why* they would greet someone were more creative (fluent and original) than those who were required to generate *ways* to greet someone. The authors argued that this was because the former likely required more abstract thought, whilst the latter required more concrete thought. They concluded that priming temporal distance was beneficial specifically for abstract thinking. In another experiment, the authors found that it was not necessary to encourage temporal distancing within the specific task context to observe improvements in creativity. They asked participants to imagine their lives by inviting them to "travel in time" to the following day (proximal condition) or the following year (distal condition) for a period of two minutes. Following this, and a short questionnaire about their mood, they then engaged with a creative generation task, where they had to give ideas on how a room design could be improved. Participants were more creative if they had been required to travel in time to the distant future prior to the task, rather than the near future. The authors concluded that thinking about life in a distant time perspective, shifted cognitive processing in a way that influenced creative performance and participants can be primed to make this shift prior to engagement with a task.

5.2 Psychological Distance and Children's Executive Function/ Creativity

Few studies have explored the effects of psychological distance from a developmental perspective. Of these, some have shown that young children can benefit when psychological distance is created in an experimental setting. For example, children are better at delaying gratification when they are encouraged to mentally transform an appetising reward (e.g. marshmallows) into a more neutral object (e.g. a fluffy cloud) (Mischel & Baker, 1975).

Distancing from the self has also shown to improve children's executive function (White & Carlson, 2016). Children completed the Minnesota Executive Function Scale for Early Childhood, a seven-level card sorting task (Carlson & Schaefer, 2012), whilst taking on perspectives that varied in distance from the self. In the control condition, children received no manipulation. In the self-immersed condition, children were encouraged to focus on what they were thinking and how they were feeling when the task became difficult e.g. "I want you to ask yourself, "Where do I think this card should go?" (pp. 422, White & Carlson, 2016). In the third-person condition, children were encouraged to talk about themselves in the third person when it became difficult e.g. "Some kids like talk to themselves using their own name when it gets hard. That's what I'd like you to do today. I want you to ask yourself, "Where does [child's name] think this card should go?"' (pp. 422, White & Carlson, 2016). Finally, in the exemplar condition, children were asked to take on the perspective of another character such as Batman or Dora the Explorer e.g. "In this game, I want you to ask yourself, "Where does [Batman] think this card should go?"' (pp. 422, White & Carlson, 2016). Five-year-olds who took on a self-distanced perspective performed significantly better on an executive function task, either through third-person self-talk or, even more so, by taking on the perspective of another (e.g. Batman, Dora the Explorer). Children made fewer perseverative errors and showed more purposeful control over their actions on a card sorting task when the distance from the self was increased. These results demonstrated the positive effect of self-distancing on children's goal-directed action.

Psychological distance has also been studied in relation to children's creativity. Liberman, Polack, Hameiri and Blumenfeld (2012), explored the effect priming spatial distance has on children's performance on creativity measures. They manipulated spatial distance by showing 6- to 9- year old children a series of photographs. In the distancing condition, they were shown photos from the very near (a zoomed-in picture of their pencil on their school desk) to increasingly distant perspectives (the classroom, the school building, the local area right up to the final picture of the Milky Way). In the proximity condition, children saw the same pictures, but in the reverse order from the very distant (the Milky Way) to the proximal (pencil on their school desk). Following this spatial distance priming exercise, children completed the Tel Aviv Creativity Test (TACT) as a measure of their creative performance. Children in the distancing condition produced significantly more ideas on the creativity test and were more original in their responses, compared with children in the proximal condition. This finding was the first to demonstrate the effect of spatial distancing on abstract mental construals in children, demonstrating that this effect is present by the time they reach early school age. The implications of this study are significant, suggesting that children's creative performance can be improved by a simple visual task which encourages abstract thought.

In the experiments in this chapter, I explore whether priming abstract thinking, via spatial distance priming, affects children's likelihood to solve a tool innovation problem, the Hooks task. In the first of these experiments, I investigate spatial priming in relation to innovation, and whether the finding that spatial priming improves creativity (Liberman et al, 2012) can be replicated.

5.3 Experiment 6

Given the benefits children have reaped from self-distancing in relation to their goal-directed action (Mischel & Baker, 1975; White & Carlson) and spatial distancing in relation to their creative performance (Liberman et al, 2012), I was keen to investigate whether the findings of Liberman et al (2012) might extend to a novel tool-innovation task (Hooks task). At present, it is unclear whether children's tool innovation performance could be enhanced by encouraging them to think in a more abstract way. Creative problem solving requires individuals to produce novel problem solutions (Mumford et al, 1991), rather than relying on previously acquired solutions. With this in mind, the Hooks task requires creative problem-solving, including tool innovation. Although in the previous chapter, children's tool innovation was not predicted by their creative potential (measured by divergent thinking), it is possible that priming children to think in a more abstract way which primes creativity, could improve their tool innovation on the Hooks task (also see Chapter 4, Introduction for how tool innovation might relate to creativity). It is also possible that solving innovative tool problems such as the Hooks task, where there is only one correct solution, is more reliant on a more concrete, convergent style of thinking (see Discussion of Chapter 4). If this were the case, priming abstract or divergent thinking might not benefit innovation.

In the current study, I investigated whether children's performance on the Hooks task was affected by spatial distance priming. In two conditions, children were either exposed to spatial distance priming from the near to far (Distancing) or from the far to near (Proximity). In an attempt to replicate the findings of Liberman et al (2012), children then completed a creativity measure as well as the Hooks task.

I hypothesised that SDP might similarly enhance children's tool innovation performance. I expected that if a difference in performance on the Hooks task was to be observed, it would be facilitated when spatial distance was increased (Distancing conditions) and abstract thinking was most likely. This would suggest that abstract thinking is implicated in generating the solution to the Hooks task. However, it is also possible that children might perform better when spatial distance is decreased (Proximity conditions), which would suggest that perhaps more concrete thinking is required to solve the Hooks task. Finally, we might observe no significant differences between the two SDP groups in terms of their tool-innovation performance. As such, I would conclude that psychological distance priming does not influence later performance on a tool-innovation task.

5.3.1 Method

5.3.1.1 Participants

The participants were 98 children (52 boys and 46 girls) aged 5- to 7- years (M = 6;8, R = 5;7 – 7;6) from one mainstream school in the West Midlands, UK. There were forty-one 5- to 6-year-olds and fifty-seven 6- to 7-year-olds. The ethnic composition of the sample was not recorded.

5.3.1.2 Materials

5.3.1.2.1 Priming of spatial distance

The priming procedure was that used by Liberman et al (2012), in which stimuli of increasing spatial distance are presented on a laptop screen. The proximal stimuli consisted of pictures taken at the participants' school. Distal stimuli were pictures which were downloaded from the internet. The 16 pictures presented were (in order from proximal to distal): a pencil on a desk, a pencil and a pencil case on a desk, a desk, a classroom, a classroom door, the school building, the school's street, a map of the school's local area, a wider area map, a regional map, a UK map, a world map, the Earth from space, the solar system and the Milky Way. (See Fig. 8 for an example of the distal and proximal stimuli used).

Fig. 8. *Example of proximal stimuli (classroom) and distal stimuli (Earth) used in the spatial priming procedure in Experiment 6.*

5.3.1.2.2 Creativity test

To measure creativity, children completed a task adapted from Milgram, Milgram and Landau’s (1974) Tel Aviv Creativity Test (TACT). These measures bear similarities with the Circles and Object Uses Tasks used in Chapter 4 of this thesis. The TACT is an adaptation of Wallach and Kogan’s (1965) creativity test and has been widely used with samples of children as a valid measure of creativity. Like previous studies (e.g. Ziv & Keydar, 2009; Liberman et al, 2012) I used a shortened version of the test. This was to ensure that the total time testing children in one sitting was appropriate and not overwhelming for them. Children were asked four questions and asked to produce as many ideas as possible. This included two verbal, “different uses” items (“What are all of the different things you can do with a shoe?” and “What are all of the different things you can do with a chair?”). and two visual “meanings of shapes” items (“What are all of the things this shape could be?”). For the visual items, the shapes (a circle and a square) were presented on a laptop screen placed in front of the child. Data was coded on two levels: fluency and originality. I defined fluency as the total number of responses children made. Original items were those which were made by fewer than 5% of the overall sample. The participant's number of original items was divided by their total number of responses to produce an originality score. I looked at originality here in order to try to replicate the original study by Liberman et al (2012).

5.3.1.2.3 Hooks Task

The apparatus was a transparent plastic tube (30cm length; opening 4cm in diameter) attached to wooden base (55cm x 55cm). At the bottom of the tube there was a small bucket containing a sticker. The bucket had a wire handle which required a hook to retrieve it from the tube. This was the newer version of the apparatus, as was used in Chapter 3, Experiment 4.

5.3.1.3 Procedure

Children were sat in a quiet area outside of their classroom, at a table, seated next to a female experimenter (CW). Children were allocated by their class list to either the Distancing HC, Distancing CH, Proximity HC or Proximity CH condition. In the Distancing conditions, pictures were presented in order from proximal to distal. In the Proximity conditions, pictures were presented in order from distal to proximal. All children completed the spatial distance priming first. Half of children in each condition then completed the Hooks Task, followed by the Creativity Task (Distancing HC and Proximity HC). The other half of children in each condition completed the Creativity Task, followed by the Hooks Task (Distancing CH and Proximity CH).

Children were advised that they were going to be shown some pictures, some of which might be familiar and others that may not. They were told that they could ask any questions that they like, at any time. Each picture was presented for 10 seconds and the experimenter also told the child what the picture was e.g. “Here you can see a picture of a pencil on a desk”. At the end of the distance priming, children were given a sticker reward for taking part in the first activity.

Next, children completed the Hooks and Creativity Tasks in the order according to their condition. In the Hooks Task, the tube apparatus was placed on the table, directly in front of the child with the pipecleaner placed next to it (see Fig. 4). Children were told that they were going to play a game to try and win a sticker. They were told that if they were able to retrieve the bucket from the tube, they could keep the sticker. The experimenter then pointed out a straight 30cm pipecleaner placed next to the apparatus and told the child: “Here is something that can help you. You can try anything you like.” Children were given up to 2 minutes to complete the task. When children stopped engaging with the task, neutral prompts were given. If a child failed to make a hook after two minutes, they were asked a final time “Is there anything else that you would like to try?” Children were given a further 30 seconds if they wanted to attempt again. Following this, the trial was ended. Children who failed to make a hook of their own were given a premade hook in order to retrieve the sticker.

In the Creativity Task, children were given the opportunity to take part in an activity to win another sticker. They were advised that they were going to be asked a series of questions and that they should try to come up with as many different ideas as they could. Children were asked the questions in a fixed order and were given one minute for each item, to produce as many ideas as possible. Their responses were recorded on a Dictaphone and live by the experimenter. All children received a sticker at the end of the activity.

5.3.2 Results

There were no effects of gender on either of the tasks (lowest p = .181), therefore all data were collapsed into one sample. Descriptive statistics for the creativity task are presented in Table 8 below.

Table 8. *Experiment 6: Children's performance on the Creativity Task.*

	Mean	Minimum Score	Maximum Score
Fluency (total number of responses)	18.28	7	28
Originality (proportion of original responses)	9.95	0	0.93

5.3.2.1 Effect of Spatial Distance Priming on Creativity Scores

Liberman et al (2012) found that children in the Near-Far SDP condition were subsequently more fluent and original on a creativity task. I ran analysis to see if our results replicated this finding. I compared performance in Distancing CH and Proximity CH because children in these conditions completed the creativity measure immediately after the spatial priming warm-up.

5.3.2.2 Fluency Simple Analysis

Fluency was defined as the total number of responses a child gave. An independent samples t-test showed no significant difference between the fluency scores of children aged between 5- and 7- years in Distancing CH (M = 18.58, SD = 6.66) and Proximity CH (M = 18.00, SD = 4.26); t (46) = .36, p = .719.

For completeness, I also ran separate analyses for the two age groups (5- to 6- year-olds and 6- to 7- year olds), since the original sample tested by Liberman et al (2012) did not include children younger than 6 years. Independent samples t-tests yielded no significant results (lowest p = .482).

5.3.2.3 Originality Simple Analysis

Original items were defined as responses which were given by fewer than 5% of the sample. Originality was coded separately for each year group. Since responses where the wordings were different could be interpreted as original responses, all responses were second-coded by a blind-coder. For example, the responses “sleep on it” and “*pretend* to sleep on it” were treated as different responses, whilst “sleep on it” and “sleep in it” were not. Cohen's κ was run to determine if there was agreement between the two coders on which items were original and which were not. There was near perfect agreement (Landis & Koch, 1977) between the two coders' judgements, κ = .91 p < .001. Percentage agreement between the two coders was 95.42%.

An independent samples t-test showed no significant difference between the originality scores of children aged between 5- and 7- years in Distancing CH (M = .47, SD = .20) and Proximity CH (M = .45, SD = .18); t (46) = .25, p = .804. Separate analyses for the two age groups (5- to 6- year-olds and 6- to 7- year olds), also yielded no significant differences between originality scores in Distancing CH and Proximity CH (lowest p = .470).

5.3.2.4 Creativity Test

A three-way analysis of variance (ANOVA) examined the effect of direction of spatial distance priming (Distancing/Proximity), task order (Hooks task first or second) and school year group on fluency (the total number of creativity items produced). This yielded no significant main effects or interactions (highest F = 1.42, lowest p = .24).

A three-way ANOVA examined the effect of direction of spatial distance priming (Distancing/Proximity), task order (Hooks task first or second) and school year group on originality (proportion of responses produced that were produced by less than 5% of the sample) in the creativity measure. This also yielded no significant main effects or interactions (highest F = 2.39, lowest p = .126).

5.3.2.5 Performance on Hooks Task

Success on the Hooks task was defined as making a functional hook, regardless of whether the child managed to successfully retrieve the bucket from the tube. This success criterion was implemented in order to avoid underestimating rates of innovation. A functional hook was defined as one of an appropriate size to make retrieving the bucket possible. Subsequent studies have suggested that modifying a material, particularly reshaping, to make a novel tool is especially difficult for children (Voigt, Pauen, & Bechtel-Kuehne, 2019. Therefore, if children could do the critical part of innovating the correct tool within the time frame, I wanted this to be coded as success. This is discussed further in the General Discussion of this thesis.

Table 9 shows the frequency of success on the Hooks task in Experiment 6 by condition. Chi-squared analysis had revealed no significant effects of age on success on the Hooks task χ^2 (1, 98) = 2.38, p = .123. However, for completeness and for the purposes of comparison with the sample used by Liberman et al (2012), I analysed the two age groups separately (5- to 6- year-olds and 6- to 7- year-olds. Across 4 conditions, Freeman-Halton Extensions of Fisher's Exact Test showed no significant effect of experimental condition on Hooks Task success in 5- to 6- year-olds (n = 41, p = .789) and a significant effect of experimental condition on Hooks task success in 6- to 7- year-olds (n = 57, p = .038).

Table 9. Experiment 6: *Children's performance on the Hooks task by condition.*

Age group	Condition (n)	Success on Hooks task	Failure on Hooks task
5 to 6	Distancing HC (10) (Near-Far > Hooks > Creativity)	5	5
	Distancing CH (11) (Near-Far > Creativity > Hooks)	7	4
	Proximity HC (10) (Far-Near > Hooks > Creativity)	5	5
	Proximity CH (10) (Far-Near > Creativity > Hooks)	4	6
6 to 7	Distancing HC (15) (Near-Far > Hooks > Creativity)	11	4
	Distancing CH (14) (Near-Far > Creativity > Hooks)	12	2
	Proximity HC (14) (Far-Near > Hooks > Creativity)	5	9
	Proximity CH (14) (Far-Near > Creativity > Hooks)	10	4

Post-hoc comparisons were run to establish which conditions were significantly different from one another for 6- to 7- year-olds, starting with the conditions where performance was most different. To avoid Type I Error, a Bonferroni correction was conducted based on the total number of possible comparisons that could be made. The new significance value was the alpha-value ($\alpha_{original}$ = .05) divided by the number of possible comparisons (6): ($\alpha_{altered}$ = .05/6) = .008. Children performed best on the hook-making task in Distancing CH and least well in Proximity HC and therefore this was the first comparison run. Children were significantly better at Hooks task in Distancing CH compared with Proximity HC, χ^2 (1, 28) = 7.34, p = .007.

Although the comparisons between Proximity HC, Distancing HC and Proximity CH failed to reach the Bonferroni corrected significance value (smallest p = 0.42), it is worth noting that children's performance on the Proximity HC condition appears different to the other three conditions when examining the raw data, and that the performance of one or two children has a large impact on the statistical tests. Therefore, I concluded that the priming manipulations were having some effect on tool innovation and investigated this further in future studies.

5.3.3 Discussion

In Experiment 6, children aged between 5 and 7 years were presented with a series of pictures before completing a creativity task and tool innovation task (order of tasks counterbalanced). In the Distancing conditions, these series of pictures began with a zoomed-in image of a child's pencil on a school desk and gradually progressed to perspectives that were more spatially distant – the whole school desk, the classroom, school, local area, map of the World and so on until the final image of the Milky Way galaxy. In the Proximity conditions, these images were shown in the reverse order.

I found that 5- to 7- year olds' performance on the creativity measure was not affected by SDP condition. I failed to replicate the finding that spatial distancing improves fluency and originality on a creativity measure (Liberman et al, 2012). Although our creativity measure included some of the same items as those used by Liberman et al (2012), it was not identical and contained fewer items. It is possible this is the reason I failed to replicate their original finding.

I also found that 5- to 6- year olds' tool innovation was not affected by SDP condition, or the order of task presentation (whether they completed the creativity measure before or after the tool innovation measure). Whilst it is possible that SDP does not affect tool innovation in this age group, it is also possible that the younger children were not as familiar with the stimuli used in the priming task. Since no effects were observed in this age group and given that Liberman et al (2012) did not use their spatial priming measure with children younger than 6, subsequent studies in this series focused on 6- to 7- year olds.

I found that 6- to 7-year-olds' performance on the Hooks task was affected by condition. Children were least likely to innovate a tool when the Hooks task followed on directly from Proximity priming. The greatest difference observed was between those children in Distancing CH and Proximity HC, although the raw data shows the absolute numbers of children who successfully innovated a hook in Distancing HC, Distancing CH and Proximity CH were similar: 11/15, 12/14 and 10/14 respectively. There are several possible explanations for this. First, Distancing priming may have facilitated children's subsequent tool innovation. However, this fails to explain why those children in the Proximity CH showed similar levels of tool innovation success. One possible explanation for this could be that the creativity measure which came between the SDP and the Hooks task, also facilitated tool innovation. The creativity measure may have given children a similar "priming" effect to the Distancing priming, which facilitated creative thinking and thus improved their subsequent tool innovation. Secondly, it could be the case that children in the Proximity HC condition are inhibited by the Proximity spatial priming, without the intervening creativity measure. In order to distinguish between these possibilities, it would be necessary to compare children's performance on the Hooks task to baseline condition, where children receive no spatial priming before completing the Hooks task.

Experiment 7 aimed to explore the effect of the direction of spatial priming on Hooks further, by including a baseline condition. I wanted to determine whether children's tool innovation is improved by spatial distancing priming, inhibited by proximity priming or unaffected altogether. The addition of a baseline condition offered the opportunity to be able to make these comparisons. This also provided an opportunity to replicate the findings from Experiment 6, which suggested that spatial distancing priming facilitated children's subsequent tool innovation.

When directly comparing Hooks innovation performance following distancing or proximal SDP (Distancing HC versus Proximal HC), twice as many children were successful in the distancing condition. Although this failed to reach the Bonferonni corrected p value (p = .042), I felt justified that this warranted further investigation. Experiment 7 aimed to explore the effect of direction of spatial priming on children's tool innovation. In order to focus specifically on the relationship between spatial priming and innovation and having failed to replicate Liberman et al's (2012) finding, the creativity measure was dropped from the subsequent experiments.

5.4 Experiment 7

5.4.1 Method

5.4.1.1 Participants

The participants were 56 children (30 girls and 26 boys) aged 6- to 7- years (M = 6;11, R = 6;5– 7;4) from one mainstream school in the West Midlands, UK. The ethnic composition of the sample was not recorded.

5.4.1.2 Materials

5.4.1.2.1 Priming of spatial distance

The priming procedure was the same as in Experiment 6, although some of the picture stimuli were changed e.g. the classroom, school and local area, to be relevant to the children in this sample.

5.4.1.2.2 Hooks Task

The same Hooks task apparatus was used as in Experiment 6.

5.4.1.3 Procedure

Children were sat in a quiet area outside of their classroom, at a table, seated next to a female experimenter (CW) who live coded the experiment. A second coder was present at 25% of test trials and agreement on successful hook innovation between the coders was 100%.

Children were allocated by their class list to one of three conditions: Distancing, Proximal or Baseline. During the first phase of the experiment, children were shown a series of images on a computer screen. All children saw the same images, although the order of their presentation was manipulated by their experimental condition. In the Distancing condition, children were shown pictures of stimuli in order from proximal to distal. In the Proximal condition, children were shown pictures in order from distal to proximal. In the Baseline condition, the order of the pictures was randomised. Following the presentation of pictures, all children completed the Hooks task.

5.4.2 Results

Success on the Hooks task was defined as making a functional hook, regardless of whether the bucket was retrieved within the given time limits. There was a significant effect of gender (boys more successful than girls) on likelihood to make a hook, χ^2 (1, 56) = 4.60, p = .032. However, earlier in this thesis, in Experiment 3, a significant effect of gender on performance in 4- to 5- year-olds was observed in the opposite direction, with females performing better than males. These findings are noted for future investigations on gender differences and problem solving. However, given that the two observed gender differences in this thesis are contradictory and that this task has been run many times without significant effects of gender being observed, they will not be discussed further.

Performance across conditions is shown in Table 10 below. First, I ran an omnibus Chi Square to compare performance on the three conditions - χ^2 (1, 56) = 16.95, p < .001. Next, I ran post hoc Chi Squares to compare performance on pairs of condition. Children in the Distancing condition showed the greatest success on the Hooks task. To avoid Type I Error, a Bonferroni correction was conducted based on the total number of possible comparisons that could be made. The new significance value was the alpha-value ($\alpha_{original}$ = .05) divided by the number of possible comparisons (3): ($\alpha_{altered}$ = .05/) = .017. Children in the Distancing condition were significantly better at innovating a hook than those in the Baseline condition, χ^2 (1, 37) = 16.88, *p* = <.001 and in the Proximal condition, χ^2 (1, 38) = 5.73, *p* = .017.

Although it appeared in the raw data that more children were successful in the Proximal condition compared with the Baseline condition, this failed to reach the Bonferroni corrected p-value for significance, χ^2 (1, 37) = 3.98, p = .046.

Table 10. Experiment 7: *Success and failure to innovate a hook on the Hooks task, following different spatial priming conditions.*

Condition (n)	Success on Hooks task	Failure on Hooks task
Distancing (19)	16	3
Proximal (19)	9	10
Baseline (18)	3	15

5.4.3 Discussion

Children were more successful at tool innovation following spatial distancing, compared with the proximal priming and baseline conditions. This provides further support for the findings in Experiment 6, suggesting that spatial distancing improves children's tool innovation performance.

Interestingly, children were least successful at tool innovation when in the Baseline condition, where the priming stimuli were presented in a randomised order. In both the distancing and proximal conditions, the series of images were presented in an order which is likely to have become predictable to children. In the distancing condition, images were getting increasingly far away and in the proximal condition, images were of objects that were increasingly close. However, the images presented in the baseline condition were not obviously related or ordered and as such, children were unlikely to be able to predict which object they would be shown next. Since children were poorer at innovation in the baseline versus the proximal condition, it is possible that children were negatively affected by the random and unpredictable nature of the images presented in the warm-up.

I felt that this was a finding worth further investigation. In Experiment 8 I explored whether children's innovative problem solving is affected by levels of predictability in their pre-test experiences. It is possible that feelings of unpredictability give rise to negative affect, which in turn hindered children's innovation. I wanted to know if children are better at tool innovation when their pre-test experiences are predictable rather than unpredictable.

5.5 Experiment 8

The third experiment in this series included three conditions. In the Distancing condition, children completed the same spatial distancing warm-up phase as in Experiments 6 and 7. In the Predictable warm-up phase, children were shown a series of images belonging to the same category (animals), and thus were somewhat predictable in their nature. In the Unpredictable warm-up phase, children were shown a series of unrelated images from a range of categories (e.g. gloves, a bouncy castle, a cat).

5.5.1 Method

5.5.1.1 Participants

The participants were 58 children (20 girls and 38 boys) aged between 6 and 7 years (M = 7;4, R = 6;11 - 7;10) from one mainstream school in the West Midlands, UK. The ethnic composition of the sample was 70.7% White, 20.7% Black and 8.6% Asian.

5.5.1.2 Procedure

Children were sat in a quiet area outside of their classroom, at a table, seated next to a female experimenter (CW). Children were allocated by their class list to one of three conditions: Distancing, Predictable or Unpredictable. All children completed a priming phase that consisted of looking at a series of images, followed by the Hooks task.

In the Distancing condition, children began with the same spatial distance priming phase as in Experiments 6 and 7. Sixteen images of increasing spatial distance were shown to children on a computer screen. Children then completed the Hooks task. In the Predictable condition, children were shown 16 pictures of animals (see Fig. 9) Children then completed the Hooks task. In the Unpredictable condition, children were shown 16 pictures from a range of semantic categories (see Fig. 9). Children then completed the Hooks task.

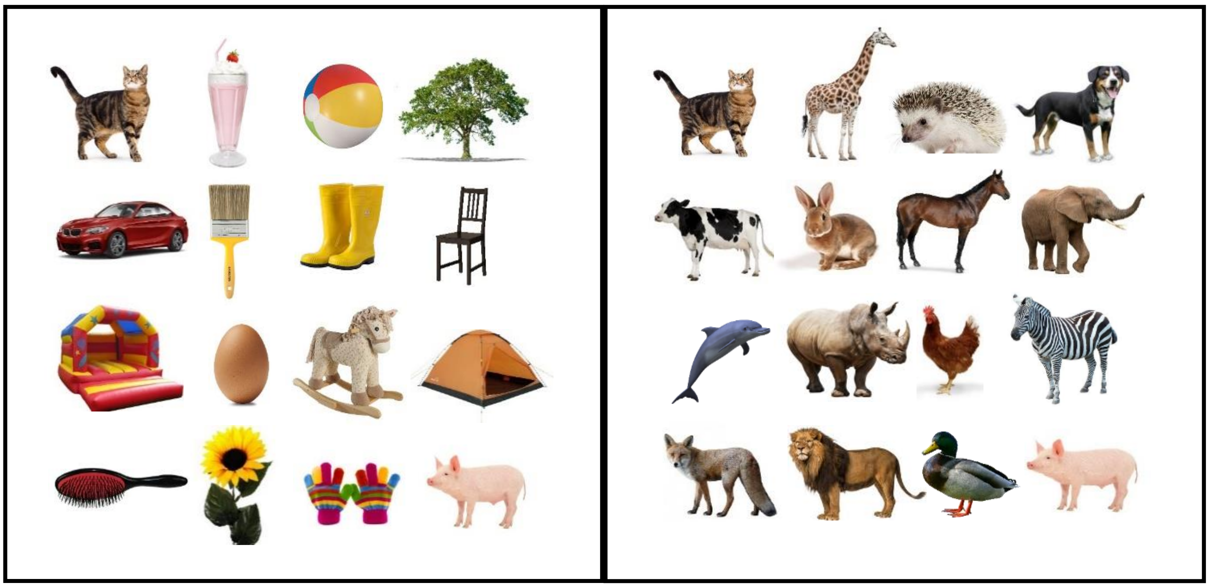

Fig. 9. *Images that were presented to children in the warm-up phases in Experiment 8: Unpredictable condition on the left, Predictable condition on the right.*

5.5.2 Results

There was no significant effect of gender on success in the Hooks task, χ^2 (1, 58) = .27, p = .602. Therefore, all data were combined for subsequent analyses.

Table 11 shows children's performance on the Hooks task across conditions. Children's performance on the Hooks task was not significantly different between conditions, χ^2 (2, 58) = 2.83, p = .242.

Table 11. *Experiment 8: Success and failure to innovate a hook on the Hooks task in Experiment 8, following different priming conditions.*

Condition (n)	Success on Hooks task	Failure on Hooks task
Distancing (19)	11	8
Predictable (20)	16	4
Unpredictable (19)	11	8

5.5.3 Discussion

The aim of this experiment was to examine whether the predictability of the warm-up phase influenced subsequent tool innovation and how this compared with a spatial distancing warm-up. In the Spatial Distancing condition, images were presented in spatial order and were therefore likely to have been somewhat predictable. In the Predictable condition, images belonged to the same category 'animals', and therefore children were likely to have been able to predict that the next picture would be another animal. In the Unpredictable condition, images were random and therefore it is unlikely children would have been able to predict what image would be presented next. I observed no significant differences in children's performance on the Hooks task between conditions.

One possibility is that the warm-up phase did not successfully manipulate children's feelings of predictability. Even though children would have been unlikely to predict the next image in the series in the Unpredictable condition, children were not explicitly required to do so, nor was their attention drawn to this by the experimenter. In addition, although children might have been able to predict that an animal would be shown next in the Predictable warm-up or make accurate predictions in the spatially ordered warm-up, they may not have been able to predict the exact image which was presented. As such, children's experiences of how accurate their predictions of the next image were may have been similar across all three conditions.

It is also possible that children's tool innovation performance was simply unaffected by their feelings of predictability during the warm-up phase or that they were not trying to predict the next image in the presentation at all. The warm-up phase contained no explicit instructions or task demands, except for children to watch as the images were presented to them. In Experiment 7, children in the Baseline condition, who were shown the spatial images in randomised order, showed lower rates of innovation, compared with children in the Spatial distancing and Proximal conditions. I hypothesised that poor performance could have been related to the unpredictable nature of the order that images were presented in the Baseline condition and this unpredictability may have negatively affected subsequent tool innovation. I designed Experiment 8 with this finding in mind, attempting to manipulate predictability in the warm-up phase. However, the images of objects used in the Unpredictable condition in Experiment 8 were different to the types of images used in the baseline condition in Experiment 7. For example, it is likely that the images in the Unpredictable condition were instantly recognisable to children whilst some of the images in the Baseline condition in Experiment 7 might have been unfamiliar for children, especially when placed outside of the context of their spatial order. For example, a picture of the Milky-

Way might not have been recognisable to some children. This may have given rise to feelings of uncertainty or reduced confidence and therefore affected subsequent tool innovation performance.

Future research might explore this finding further to determine whether prior experiences which create feelings of uncertainty might negatively affect children's likelihood to innovate tools on subsequent problems. One way that this could be investigated would be to show children pictures of a series of familiar objects and name them e.g. "ball" and a series of unfamiliar, novel objects, like the novel tools "dax" and "blicket" used by Casler and Kelemen (2007). Children could be directly asked about whether they recognise these objects, to obtain a more objective measure of whether or not children experience uncertainty. Children's subsequent performance on tool innovation problems could then be compared, along with a baseline.

5.6 General Discussion

Across three experiments I explored the effect of spatial priming on children's tool innovation. In Experiment 6, six- to seven- year-olds were significantly better at innovating a hook tool when they had first experienced Distancing spatial priming and completed a creativity task, versus when they attempted the Hooks task immediately after Proximity priming. I failed to replicate the finding of Liberman et al (2012) and found no relationship between direction of spatial distance priming and creativity. The creativity measure was dropped from the studies which followed, in order to focus on the potential relationship between spatial distance priming and tool innovation.

In Experiment 7, I explored the effect of spatial distance priming on tool innovation directly, including a baseline condition for comparison. Children who completed spatial distance priming were significantly better innovators than those who were in the proximity priming condition and the baseline condition, suggesting that spatial distance priming promotes subsequent tool innovation. I also found that children were significantly poorer innovators following the baseline condition compared to the proximity priming condition: children were less likely to innovate a hook on the Hooks task if they had been shown the same spatial images in a randomised order rather than in spatial order from the most distant to most proximal. I hypothesised that children's poor performance in the baseline condition could have been due to the unpredictable nature of the warm-up phase. Since the images were presented in a random order, children would not have been able to anticipate the next image in the series. Conversely, children might have been more able to predict the next image in the series in the proximal priming condition. The third experiment in this series sought to test this hypothesis.

In Experiment 8, I aimed to determine whether children's tool innovation was sensitive to the levels of predictability in the warm-up phase. In a warm-up phase, children were either shown spatial distance priming stimuli, a series of images belonging to the same category (predictable) or a series of random images (unpredictable). All children then completed the Hooks task. I observed no significant differences in Hooks task success between conditions. It is not clear why I observed this pattern of results, although there are a number of possible explanations.

First, it is possible that children's feelings of predictability on an unrelated task do not affect their subsequent likelihood to innovate the solution to the Hooks task. Children's poor performance in the baseline condition in Experiment 7 might be explained by another cause, for example, induced negative affect, as a result of children feeling confused by the random order images appeared in. This is discussed further in the General Discussion of this thesis.

Alternatively, children's experiences of predictability in this experiment may have in fact been similar across conditions and my attempt to manipulate this may not have been successful.

An alternative explanation for why performance did not significantly differ in the last experiment in this chapter, is that each of the warm-up phases offered an opportunity for children to think in a more abstract way or created psychological distance. The images which children were shown, of animals, bouncy castles, balls etc., may have sparked some children to think about temporally distant events, associated memories and experiences related to those images or to engage in imaginative thinking, especially in the absence of any other instruction related to observing the pictures. This may have been sufficient to divert children's attention from their immediate surroundings to engage in abstract thinking.

Finally, children's performance across conditions in the last experiment could have been at baseline and spatial priming may not have facilitated innovation in that sample. This seems a less likely explanation, given the positive effects of spatial priming observed in the previous experiments. Future studies should investigate further how abstract thinking can be primed and the effect this has on children's likelihood to innovate tools to solve problems.

In the first two experiments in this chapter, I observed children's tool innovation was best when it was preceded by a spatial distancing warm-up. Priming psychological distance has previously been shown to benefit children's ability to think creatively (Liberman et al, 2012). These studies suggest that creating psychological distance can reap a similar benefit in terms of children's tool innovation, making them more likely to bring to mind and make a novel tool to solve a physical problem. These findings have far-reaching applications, including in the classroom. Future research might seek to explore how priming spatial distance and other types of psychological distance, e.g. temporal, hypotheticality might influence children's problem-solving behaviour. If simple priming measures, such as showing children a series of images, can improve children's innovative problem-solving, this would be easy to incorporate into the classroom and could benefit children's achievement at school.

The aim of this chapter was to explore whether encouraging children to think about spatially distant perspectives, may promote abstract thinking and drive innovative problem solving. This is a new area of research which requires further investigation to substantiate the claim that spatial priming improves innovation. In future, comparing performance on the Hooks task following spatial priming to a baseline where no priming is given, will strengthen our understanding of the relationship between spatial priming and innovation. However, the findings from the first two studies do provide tentative support for this hypothesis. The findings are especially interesting given that children's innovation was supported without having to give them information about how to solve the task. In the next chapter I look at how a different type of priming might affect children's subsequent innovation on the Hooks task.

Chapter 6

Can priming an analogical problem-solving mindset improve children's performance on the Hooks task?

6.0 Introduction

Analogical reasoning has been widely considered a hallmark of human intelligence (Sternberg, 1977; Holyoak, Junn & Billman, 1984) and is prevalent in prominent theories of general human intelligence (see Sternberg, 1977 for a brief overview). Analogical reasoning can be defined in simple terms as the ability to make comparisons, by drawing on our knowledge and experiences. We reason by analogy when we make decisions, judgements and solve problems.

Children show that they can use analogy to solve problems from an early age. The basic experimental paradigm for assessing analogical transfer in children is to present them with base story analogues that demonstrate problems and solutions and observe their subsequent solutions to analogous target problems. Holyoak et al (1984) demonstrated that children as young as 4 years can use analogies to solve problems. Children were required to move balls from one bowl to another, using a variety of materials presented to them including a walking cane, plasterboard, string and a cardboard tube. One of the bowls was placed outside of their reach and children were required to solve the problem without leaving their seat. Children either attempted this task straight away or having first listened to two base stories, in which characters faced analogous problems and used solutions which the children could transfer to the subsequent target problem. For example, a genie wanted to move his jewels from his old bottle to a new bottle which was beyond his reach. In the base story, he used his 'magic staff' to pull the new bottle closer in order to put his jewels inside. All of the children who heard this story used an analogous solution when they faced the transfer ball problem themselves: they used a cane to pull a bowl closer. By contrast, only one child in the control and alternative story group produced the cane solution spontaneously for themselves, suggesting that children were indeed drawing the analogy between the transfer problem and the problem faced by the genie in the base story.

Chen & Daehler (1989) investigated the effect of level of story representation and 'abstract schema training' on positive and negative analogical transfer in 6-year-olds. Children were presented with pairs of base story analogues, before being given a target transfer problem. The solution principle required to solve the transfer problem was either similar to, or differed from, the solution principle in the base stories, which formed the positive and negative transfer conditions. In the Control conditions, the stories were unrelated to the target problem. Some participants also received abstract schema training, whereby they were guided by the experimenter to recognise the common problems and solution principles in the base stories if they had failed to do so spontaneously. Overall, the study showed that 6-year-olds were capable of generalising abstract principles from stories and applying them to real problems. When children formed an abstract representation of the base stories, they were more successful at analogical transfer to the target problem. Supporting children to form an abstract representation of the base stories, via abstract schema training, further improved performance on the transfer problems in the positive conditions. The study also showed that when the base and target problems involved different solution principles, children's performance was hindered (negative conditions). As well as demonstrating that 6-year-olds were able to use analogy to solve a physical problem, Chen and Daehler (1989) also demonstrated that children's problem solving can be improved when they are explicitly guided to reason by analogy.

The ability to use analogical transfer to solve problems has also been demonstrated in younger children. The following study forms the basis of the experiment presented in this chapter. Brown and Kane (1988) investigated 3- to 5- year-olds' ability to learn to transfer solutions across problems. They wanted to see whether preschool children could develop a mindset to look for analogies as a means of solving a series of isomorphic problem pairs. Children were given three problem pairs and were required to use the information in the first problem of a pair, which they were guided to solve, to solve the problem in the second. For example, in problem one a mechanic was unable to reach a high shelf to put away his delivery of tyres and in order to do so was required to stack two tyres and stand on top of them. In the second problem of this pair, a farmer is unable to reach the top of his tractor to stack his bales of hay. The analogous solution from problem one is to stack two bales of hay on top of one another and stand on them to reach the top of the tractor. Across problem pairs they were interested to see if children would recognise the abstract rule to "transfer prior solutions" (pp. 498, Brown and Kane, 1988). Children were either asked to explain how the problems in a pair were alike, once they had solved the second problem in each pair (reflection group) or not (no reflection group). Children in the control group were given just one problem pair, after completing two irrelevant problems that did not require any transfer. Four- and five-year-old children showed a 'learning to learn' effect, even without any discussion after each problem pair and were significantly better than the control group in both the reflection and no reflection groups. By the second problem pair, the majority of 4- to 5-year-olds transferred solutions and by the third pair, 90% transferred the solution to the second problem. Children quickly picked up that they needed to use the solution to the first problem in the pair to solve the second problem. Three-year-olds were also able to transfer solutions, but only if they were encouraged to reflect on and discuss how they had solved the problems after each pair (reflection). Most strikingly, these findings suggested that four- and five-year-olds can form a 'mindset' to look for analogies across problems, without any instruction to do so (Brown & Kane, 1988). The subsequent experiments in their study also demonstrated that this learning to learn effect occurs even when the problem pairs are not in sequence. As well as children being able to transfer a solution that they have just seen demonstrated to a subsequent problem, they can also select the correct analogous solution to a problem encountered later, from a series of past experiences.

6.1 Experiment 9

Ratterman & Gentner (1988) coined the term "relational shift" to describe qualitative changes that occur in children's analogical thinking at around 5 years: early attention is on the common properties of objects whilst it later moves to the common relational structures of objects. For example, Gentner (1988) presented children and adults with metaphors such as "A cloud is like a sponge" and asked them to interpret them. Five- to seven-year-olds produced more interpretations that were based on shared physical appearances, such as "Both are round and fluffy." Older children and adults gave interpretations based on common relational structure: for example, "Both can hold water and then later give it back." In addition, when choosing between and other people's interpretations of metaphors, given a choice between an attributional interpretation and a relational interpretation, preference for relational interpretation increases across childhood into adulthood.

As has previously been noted, this qualitative shift in children's analogical thinking coincides with changes in children's tool innovation performance (Beck et al, 2016). It seems plausible that solving tool innovation problems, such as the Hooks task, relies at least in part in the ability to engage in analogical thinking. In order to solve the Hooks task children are required to recall their knowledge and experiences and apply this to a novel problem to come up with an appropriate solution.

Rather than adopting an individual differences design and looking for a possible correlation between children's ability to solve analogies and their tool innovation proficiency, I took a different approach to exploring the possible relationship between analogical reasoning and tool innovation. Chen and Daehler (1989) have shown that children's problem solving is improved when they are encouraged to reason by analogy. In Chapter 5, I observed that when children were encouraged to think more abstractly, by spatial distance priming, their tool innovation was improved. This was the first time that children's performance on the Hooks task has been facilitated without adjusting the task itself or revealing any aspect of the solution to the child. Taking this into account and considering that children can form a mindset to look for analogies to solve physical problems (Brown & Kane, 1988); I considered whether I might observe improvements on the Hooks task if children were first primed to form an analogical problem-solving mindset.

In order to explore the effect of forming an analogical mindset on children's innovation on the Hooks task, children were allocated to one of three conditions. In the Analogical Mindset condition, children listened to two pairs of base stories which involved protagonists encountering a problem and coming up with an appropriate solution. Within each pair, the problems and solutions were analogous, and children were guided to draw this analogy by the experimenter if they did not do so spontaneously. Children then went on to attempt a transfer problem following each story pair. Finally, children attempted the Hooks task, without any prior exposure to an isomorphic problem or solution beforehand. The remaining children were divided between the Problem-Solving Stories and Control Stories conditions. In the Problem-Solving Stories conditions, children listened to and were asked to recall one story from each pair in the Analogical Mindset condition, in order that they had the opportunity to listen to stories about problem-solving without the analogy element. They then attempted the Hooks task. Finally, children in the Control Stories condition listened to and recalled stories that were unrelated to problem solving, before completing the Hooks task. I hypothesised that if forming a mindset to solve problems by analogy was beneficial to children's tool innovation, I would observe superior performance of children in the Hooks task in the Analogical Mindset condition. The inclusion of the Problem-Solving Stories condition was to explore whether children particularly benefit from drawing analogies between stories of problem-solving, or if listening to examples of physical problem-solving has an equivalent effect on children's subsequent innovation on the Hooks Task. The Control Stories condition was a baseline which enabled me to look at whether children's performance in the other experimental conditions was significantly different.

6.2 Method

6.2.1 Participants

The participants were 59 children aged between 5 and 7 years, recruited from one mainstream school in the West Midlands, UK. There were 30 children (22 boys and 8 girls) aged 5- to 6- years (M = 6;0, R = 5;6 – 6;4) and 29 children (16 boys and 13 girls) aged 6- to 7- years (M = 7;1, R = 6;5 – 7;5). The ethnic composition of the sample was 93% White, 5% Black and 2% Asian.

6.2.2 Materials

Stories were the almost the same as those used by Chen & Daehler (1989) except for minor replacements of some words e.g. "parking lot" became "car park" to make them suitable for the current sample. Some aspects of the stories such as the names of the characters and sports being played were modified slightly but the problem, goals and solutions were the same.

6.2.2.1 Story analogues

Two different sets of stories were used for the Analogical Mindset condition. Each story included a goal, an obstacle to overcome, and a solution, plus other irrelevant information. Within each set, the two stories involved different central characters, objects, and themes, however whilst the underlying solution rule was the same. For the first set of stories (Set A, see Appendix 1) the solution in both stories was "reaching an object by adding something to make it rise." This solution was the same solution required to succeed in the Floating Ball transfer problem. The Floating Ball transfer problem is the same task as the Floating Ball task from Chapter 4, Experiment 5. The two stories used in Story Set B included a solution which could be applied to the ‘Combining’ transfer problem. The solution was "reaching an object by combining two items."

Children in the Problem-Solving Stories condition listened to one story from each set during their priming phase, ‘Fallen Ball’ and ‘Hungry Monkey’ (see Appendix 1).

During their priming phase, children in the Control Stories condition listened to two, unrelated stories with no problem-solving content (see Appendix 1).

6.2.2.2 Analogical Transfer Problems

6.2.2.2.1 Floating Ball Task

Apparatus was a transparent vertical tube, 22cm high and 5cm in diameter. A small ball was placed inside the tube, suspended in a little water at the bottom of the tube. Children were required to retrieve the ball from the tube, without tipping it upside down. The only solution was to pour water to raise the ball to the top of the tube. Children were presented with the following materials as potential items to help to solve the problem and retrieve the ball from the tube: a measuring cup containing water, two paperclips, a straight 30cm pipecleaner and an elastic band.

6.2.2.2.2. Combining Task

Apparatus was a transparent horizontal tube, 30cm length and 4cm in diameter, placed on a platform, 5cm higher than the desk. Inside the tube, (25cm) away from the entrance, was a small block on a cardboard platform. Children were asked to try to push the small toy block off the platform and out the other end of the tube. Children were presented with the following materials as potential items to help to solve the problem: an 20cm pipecleaner and a 10cm straw. Both items were too short individually to reach the block. The solution was to insert the pipecleaner into the straw to make a tool long enough to reach the block on the platform.

Fig. 10. *Combining Task apparatus.*

6.2.2.3 Hooks Task

The apparatus comprised of a transparent plastic tube (30cm length; opening 4cm in diameter) attached to wooden base (55cm x 55cm). At the bottom of the tube there was a small aluminium bucket (2cm x 2cm) containing a sticker. The bucket had a wire handle which required a hook to retrieve it from the tube. A straight 30cm black pipecleaner was also presented next to the apparatus. See Fig. 4 (Chapter 3).

6.2.3 Procedure

All children completed the experiment individually, with a female experimenter (CW). A second live coder was present for all experimental trials. Inter observer agreement was 100% across all tasks. Children were allocated by their class list to one of three conditions: Analogical Mindset, Problem-Solving Stories or Control Stories. All children completed a priming phase followed by the Hooks Task.

6.2.3.1 Analogical Mindset Condition

For the priming phase, children listened to two sets of stories and completed two transfer problems. First, children listened to two stories (Story Set A, Appendix 1). Children were instructed to listen carefully, because afterwards the Experimenter would ask them what had happened during the story. After each story, children were asked to recall what happened "Do you think you can tell me what happened in the story?". Children's recall was scored as either Independent or Assisted. Where key information from the story was missing, the Experimenter filled in and reminded the child of the missing parts (assisted recall). Next, the Experimenter looked for evidence of analogy being drawn. Children were asked: "The stories you just listened to, were they similar in any way? Were they alike?". Children were then asked to explain how the stories were alike. Children's level of representation was scored using the same criteria used by Chen and Daehler (1989). Children received a score between 1 (irrelevant recall) and 4 (abstract representation). For further detail on the scoring criteria used see Appendix 2. Where children failed to form an abstract representation of the two stories, the experimenter scaffolded and where necessary explicitly explained the analogy between the two stories.

Children were then presented with a transfer problem, the Floating Ball task, and told "Now we're going to play a game to see if you can win a sticker". They were presented with the Floating Ball apparatus and materials. They were told "If you can get the ball out of the tube, without tipping the tube upside down, you will win a sticker. You can use any of these things to help you". Children were given 1 minute to attempt to solve the task. If after 1 minute, children had failed to solve the task, the Experimenter prompted them to recall the solutions from the story by asking "Do you think that anything you heard in the stories might be able to help you to get the ball out of the tube?". Children were then given another minute to solve the task. If children were still unable solve the problem, the Experimenter guided them to do so “Could you try pouring the water in to the tube?”. It was recorded whether children solved the transfer problem spontaneously, after prompting or were assisted by the Experimenter.

This process was repeated for a second set of stories (Set B, Appendix 1) and transfer problem, Combining task. All children received praise and a sticker at the end of the priming phase.

Finally, children were given 2 minutes to complete the Hooks task.

6.2.3.2 *Problem-Solving Stories Condition*

For the priming phase, children listened to one story from Set A, “Fallen Ball” and one story from Set B, “Hungry Monkey”. Both stories therefore contained problem-solving, however there were no analogies between the stories in terms of the problems the characters faced or the solutions that they used. Children were advised to listen carefully because afterwards the Experimenter would ask them what had happened during the story. After each story, children were asked to recall what happened “Do you think you can tell me what happened in the story?”. Children’s recall was scored as either Independent or Assisted. Where key information from the story was missing, the Experimenter filled in and reminded the child of the missing parts (assisted recall). Children in the Problem-Solving stories and Control conditions did not attempt the physical problems. All children received praise and a sticker at the end of the priming phase. Finally, children were given 2 minutes to complete the Hooks task.

6.2.3.3 Control Condition

For the priming phase, children listened to two stories that were unrelated to problem-solving, ‘The New House’ and ‘The Zoo Visit’ (see Appendix 1). As in the other conditions, children were told to listen carefully and asked to recall what had happened in the stories.

When there were gaps in recall, the Experimenter reminded the child of the missing parts (assisted recall). Children's recall was scored as either Independent or Assisted. All children received praise and a sticker at the end of the priming phase. Finally, children were given 2 minutes to complete the Hooks task.

6.3 Results

6.3.1 Descriptive Statistics

6.3.1.1 Story analogues

After hearing and recalling both stories in Story Set A, most children (15/19) 78.95% agreed that the two stories were alike in some way. Only 4/19 children (21.05%) were scored as describing an abstract representation of the two stories for themselves, without requiring assistance from the experimenter. Those who failed to make an abstract representation were guided to do so by the experimenter. Following the second set of stories, the same number of children agreed that the two stories were alike. The number of children who described an abstract representation of the two stories without prompting increased to 10/19 (52.63%). It could be that children found it easier to draw the analogy between the two stories in Set B. However, it could also be the case that children were forming a mindset to look for analogies, as has been suggested in previous studies (Brown & Kane, 1988).

6.3.2 Transfer Problems

6.3.2.1 Floating Ball Task

All but one child solved the Floating Ball Task spontaneously, without assistance. The remaining child was unable to solve the task following a prompt and so the experimenter helped them to solve the problem.

6.3.2.2 *Combining Task*

All children solved the Combining Task spontaneously and only one child required a prompt from the Experimenter to recall if anything they had heard in the stories could help them.

6.3.3 Hooks Task

There was no significant effect of gender on likelihood to innovate a hook on the Hooks task, χ^2 (1, 59) = .58, p = .448. There was also no significant effect of school year group on likelihood to innovate a hook, χ^2 (1, 59) = 2.04, p = .154, therefore all data were collapsed into one sample.

Table 12 shows children's performance on the Hooks task by condition. Children's performance on the Hooks task was best in the Analogical Mindset condition. Chi-square analysis was performed to compare children's performance between conditions. Children were significantly more likely to succeed in the Analogical Mindset condition compared with both the Control Stories condition, χ^2 (1, 39) = 13.75 p < .001 and the Problem-Solving Stories condition, χ^2 (1, 39) = 11.65, p = .001. There was no significant difference in children's performance on the Hooks task in the Control and Problem-Solving stories conditions, χ^2 (1, 40) = .72, p >.999.

Table 12. *Experiment 9: Number of children innovating a hook, or not, on the Hooks task by condition.*

Condition (n)	Success on Hooks task	Failure on Hooks task
Analogical Mindset (19)	16	3
Problem-Solving Stories (20)	6	14
Control Stories (20)	5	15

6.4 General Discussion

Experiment 9 sought to explore whether children’s tool innovation could be improved by encouraging them to form an analogical problem-solving mindset, before attempting the Hooks task. I found that children who had the opportunity to engage in analogical thinking and problem-solving were significantly more likely to innovate the solution to the Hooks task, than those children who listened to and recalled stories involving problem-solving or stories unrelated to problem-solving.

The data demonstrates a quite striking effect of the analogical mindset condition on children’s subsequent tool innovation. First, it could be the case that the priming phase in the Analogical Mindset condition was indeed successful in helping children to develop a mindset to solve problems by analogy and that this mindset helped them to solve the Hooks task. Once in a mindset to look for and solve problems by analogy, children may have been able to draw on their past knowledge and experiences to bring to mind and coordinate the solution to the Hooks task.

It is also possible that it was the experience of solving other physical problems, prior to attempting the Hooks task, which led to improvements in children’s performance. Although the problem-solving stories condition involved children listening to characters solve problems, it did not involve them engaging with physical problem solving before attempting the Hooks task. However, previous research where children have attempted multiple innovation tasks has not found evidence that children’s performance improves across tasks. Cutting, Apperly & Beck (2011) found that children did not show any positive transfer effects across two innovations task: the Hooks task and a task requiring them to unbend a tool to make a longer, straight tool needed to push out a reward from a tube. Succeeding, independently or with help, on the first task, did not increase children’s likelihood to innovate a tool to solve the second task. Future research might seek to explore this further to determine whether children particularly benefit from engaging in analogical problem-solving before engaging with an innovation task or if physical problem-solving alone may sometimes be enough to improve subsequent innovation.

In order to explore the possibility that physical problem-solving experience may have driven improved performance on the Hooks task in Experiment 9, a study ought to assign children to one of four conditions. In one condition, children should listen to pairs of base stories, followed by a transfer problem, followed by the Hooks task, as in the Analogical Mindset condition in Experiment 9. In a second condition, children should listen to the same pairs of base stories and be encouraged to draw the analogies, but not attempt any transfer problems before going on to attempt the Hooks task. In a third 'physical problem solving' condition children would attempt the same transfer problems, but without the prior base story analogues. A control condition involving no opportunity for prior analogical problem solving, analogical thinking or problem-solving before the Hooks task would also be useful to provide baseline data on children's innovation. This experimental design would enable comparison of children's performance to identify which conditions, if any, facilitate children's tool innovation and would provide further insight to what drove children's improved performance in the analogical mindset condition in Experiment 9.

Future research ought to explore further how analogical thinking might relate to performance on the Hooks task, to understand whether children benefit particularly from analogical problem solving or if priming analogical thinking via other tasks might also be beneficial. For example, children could be given a spatial analogies task which has been successfully used with children from 4 years (Gentner, 1977). Here children are required to map parts of the human body to spatial positions on a picture of a mountain e.g. "If the mountain had eyes, where would they be?". By comparing their performance on the Hooks task after a spatial analogy task, analogical problem-solving and baseline condition, we can better understand how analogical reasoning and tool innovation might be related.

The relational shift hypothesis asserts that qualitative changes in children's analogical thinking occur around the age of 5 years, when their attention shifts from focusing on the common properties of objects to the common relational structures of objects (Ratterman & Gentner, 1988). The domain-knowledge account of the relational shift hypothesis (see Introduction to this chapter) posits that the shift will occur at different times for different domains and earliest in the domains that are the most accessible to young children (Gentner, 1988). Only when children have the appropriate domain knowledge, can they begin to make relational interpretations within that domain. This would suggest that perhaps only children with the appropriate domain knowledge of tools, can then begin to use that knowledge to draw analogies that enable successful tool innovation. In this case, children who lack sufficient domain knowledge would be poor tool innovators, regardless of their analogical reasoning ability. Future studies could explore how domain knowledge about tools affects tool innovation, by giving some children more pre-test experience with tools and tool-making materials. The effect of increasing children's exposure to tools and materials on innovation could then be observed.

Another possible direction for future research would be to investigate whether those children who succeed on the Hooks task show greater analogical reasoning ability. An experiment with an individual differences study design could explore whether children's analogical reasoning ability relates to their Hooks Task performance. This could help in the pursuit of identifying characteristics of 'good innovators' and contribute to our understanding of the cognitive mechanisms which underlie tool innovation capacity. So far, attempts to identify personal characteristics which related to innovation have been unsuccessful. For example, in Chapter 4, divergent thinking was not predictive of innovation on the Hooks task.

The findings from this study, which suggest analogical problem solving helps innovation, provide a potential characteristic which might distinguish innovators from non-innovators.

What is intriguing about the results in Experiment 9 is that children were not exposed to base analogues which had problems or solutions analogous to the Hooks task. Rather, children proceeded straight from their second transfer problem, the Combining task, to the Hooks task. There were no clues given or prompts offered to facilitate the solution of the Hooks task, children were required to do so entirely on their own. Previous studies have noted children's difficulty with the Hooks task (Beck et al, 2011; Cutting, Apperly & Beck, 2011) whilst this study suggests that, without any reduction in task demands or hints about the solution, children can innovate the solution to the Hooks task for themselves.

The present study contributes to discussion about whether previous studies have driven us to underestimate children's tool innovation abilities, specifically on the Hooks task. It suggests that one way in which children can be supported to innovate tools is to have them engage in analogical problem-solving, giving them the opportunity to form a mindset to seek out analogies as a means of solving physical problems.

Chapter 7

General Discussion

7.0 Overview

This thesis aimed to contribute to our understanding of children's difficulties with tool innovation and to begin to explore some of the ways in which children's tool innovation can be supported. In this final chapter, I will begin by acknowledging some of the minor methodological differences of versions of the Hooks task that have been run in this thesis and give reasons for them. I will briefly summarise the key findings from each of the empirical chapters, draw links between them and discuss these in relation to the wider literature. I will then discuss the implications and potential applications of my findings. Finally, I will make specific suggestions about future research directions.

7.1 Methodological Differences Across the Experiments in this Thesis

Across the experiments in this thesis there are some subtle differences between the apparatus and procedures that were used for the Hooks task. For clarity, I will now summarise these differences and explain the reasons for these.

7.1.1 Apparatus

There were two versions of task apparatus that were used in this thesis. The original apparatus consisted of a transparent plastic tube (22cm length; opening 5cm in diameter) attached to a cardboard base (Fig. 11). At the bottom of the tube there was a small, wire handled bucket containing a sticker. This apparatus was used for all experiments in chapters 2 and 4.

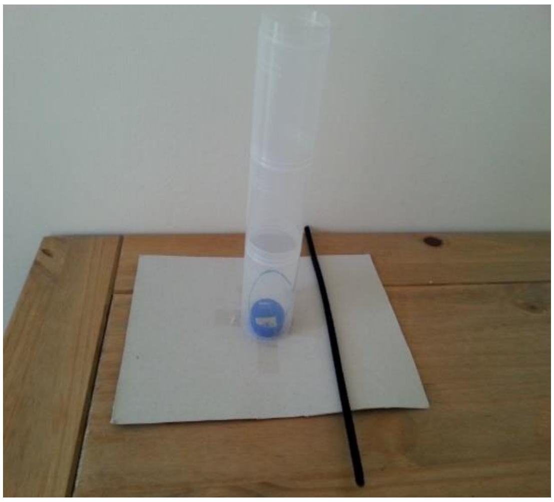 

Fig. 11. *Original apparatus for the Hooks task (pictured, left) and the updated apparatus (pictured, right).*

The old apparatus was replaced with a new and improved apparatus for all other experiments in Chapters 3, 5 and 6 (see Fig. 11). The apparatus still required the same task solution and was comprised of a transparent plastic tube (30cm length; opening 4cm in diameter) attached to wooden base (55cm x 55cm). At the bottom of the tube there was a small, metal, handled bucket which contained a sticker. The new apparatus made it more difficult for children to retrieve the bucket from the tube without making a hook. Using the old apparatus, there were a number of occasions when children were able to use a straight pipecleaner to drag the bucket up the side of the tube and retrieve it, without needing to make a hook. The smoother surface of the new apparatus' tube and the slightly narrower width made this more difficult. No child retrieved the bucket from this apparatus using an unmodified pipecleaner. The new apparatus was also heavier and sturdier which made it more durable for transporting and less likely that children would try to upturn it.

7.1.2 Distractor Items

Unlike in some previous versions of the Hooks task (e.g. Beck et al, 2011; Cutting et al, 2011) I did not include any distractor items as potential tool-making materials alongside the apparatus. This was the same across all experiments in this thesis. Children were only ever presented with a pipecleaner as a potential material to make a tool. I made this decision to increase children's chances of showing their potential for successful tool innovation, since they could not waste their time or effort on materials that would not be effective.

7.1.3 Time to Solve the Task

In Experiments 1, 2 and 3 (Chapter 2) and Experiment 5 (Chapter 4), children were given one minute to solve the Hooks task. This was consistent with previous versions of the task run with children. However, in the remaining experiments in this thesis, children had up to 2 minutes to solve the task. I made the decision to give children longer, in order to give children more opportunity to solve the task. I did this bearing in mind what was an appropriate amount of time for young children to spend away from their classroom activities and to be attempting a task without help, which they might have found difficult. I also considered the lack of improvement observed across trials in Experiment 1. Here, children were given three attempts to solve the task, made up of one, one-minute attempt and a further two, thirty-second attempts at the task. Children's performance neither improved nor deteriorated across trials. I felt it was difficult to justify allowing children much longer to attempt the task, given that it may have been an unpleasant experience for some children who were not able to reach success on their own.

Since the empirical work for this thesis was completed, research has been published which has suggested that children might perform better on tool innovation tasks when they are given more time (Voigt et al, 2019). However, in a condition which required children to make a hook from a flexible piece of wire, to retrieve a bucket from a tube (as in the Hooks task), children were poor innovators even when they had up to 10 minutes to solve the task. In light of this finding, giving children 2 minutes was likely to have been a reasonable amount of time to capture most children's capacity for innovation on the Hooks task. However, it is important that future studies looking at children's tool innovation are mindful that children have enough time to try to solve the task whilst avoiding making them feel uncomfortable being tested for extended periods of time. This research and its implications are discussed in more detail later in this chapter.

7.1.4 Bending practice

In Experiment 5, children were given a bending practice, which involved the children copying the experimenter wrap a pipecleaner around a pen. This was the first study that was done (chronologically) following on from the first three experiments, which were focused on prior experience in terms of using and seeing premade tools. In line with previous studies, I included a bending practice as a warm-up to the Hooks task. However, in the remaining experiments in this thesis I did not include a bending practice phase. I did this because I felt that an experimenter demonstrating to children how they can manipulate a pipecleaner might make some children anticipate that the experimenter might also demonstrate the solution to them. It might also have influenced how children manipulated the pipecleaner. Research has suggested that teaching limits children's spontaneous exploration and discovery. Children find out more about the properties of materials when they are free to explore for themselves, rather than being taught by an adult (Bonawitz, Shafto, Gweon, Goodman, Spelke & Schulz, 2011). I did not want to stifle children's exploration and potential for innovation by giving them pedagogical cues about how they ought to manipulate the materials before the task. In the absence of evidence suggesting that bending practice facilitates performance, I decided to omit this from the Hooks task for my future experiments.

7.1.5 Second Coding

A second coder was present for most, but not all of the experiments in this thesis. Agreement between coders on successful hook innovation was always 100% and therefore coding of the Hooks task was deemed to be robust. For all Experiments in Chapters 3, 4 and 6, a second coder was always present. These experiments included tasks other than the Hooks task or involved an experimenter interacting with the apparatus during testing and so a second coder was necessary to ensure reliability of coding. For the series of experiments in Chapter 2, the only coding required was of the Hooks task. A second coder was present for 25% of the trials in Experiment 1. Agreement between coders was 100% and therefore no second coder was deemed necessary for the remaining experiments in that series (2 and 3). In Chapter 4, Experiment 5, the experimenter and a second, blind coder coded all responses to the Object Uses task in terms of whether they were a ‘design function’, a ‘novel function’, or ‘other suggestion’. Inter-coder agreement was 80% and disagreements were resolved by a third coder. In the experiments in Chapter 5, the only live coding required was of Hooks task performance. A second coder was present for 25% of trials in Experiment 7 and agreement on successful hook innovation between coders was 100%. Responses to the creativity task in Experiment 6 were coded live by the experimenter and was also recorded on a Dictaphone. The only subjective element of coding of the creativity task was of originality of responses, which were also coded by a second blind-coder after the experiment. Agreement was near perfect. In summary, second coding was always used when there were subjective elements, such as judgements of originality or categories of responses.

7.1.6 Definition of Success on the Hooks Task

The criteria for success on the Hooks task was also changed after Experiments 1, 2, 3 and 5. Here, the criteria for success was being able to make a hook and use it to retrieve the bucket from the tube. In Experiment 5, two children made a hook but were unsuccessful in retrieving the bucket from the tube within the time limit. Therefore, in all other experiments, the criteria for success was making a functional hook. Inter-coder agreement on what was deemed a functional hook was always 100%. This was defined as a hook that was an appropriate size (i.e. not too large to not fit underneath the handle). The rationale for the new success criteria was to ensure that our results reflected children's ability to innovate tools and did not underestimate it by penalising those who failed to retrieve the bucket within the timeframe.

7.2 Summary of Findings

In the first empirical chapter of this thesis, Chapter 2, I explored the effect of prior experience with premade tools on children's tool innovation. In three studies, the role of prior experience on children's ability to innovate a hook tool to solve the Hooks task was investigated. When children were given the opportunity to use a premade hook tool, like the corvids, they were significantly more likely to innovate a hook on a subsequent attempt at the Hooks task. Children found *using* a premade hook more beneficial than only *seeing* a premade tool before innovation. In the final experiment of Chapter 2, I found that *using* or *seeing* a premade hook tool was beneficial to subsequent innovation for 6-to 7- year-olds. For 4-to 5- year-olds, using a hook was more beneficial than seeing a hook, but seeing a hook also boosted performance to levels higher than we would expect.

Taken together, these findings provided support for the idea that the most difficult aspect of tool innovation problems for children is bringing to mind the solution for themselves. I highlighted the benefit that younger children experience by being given information about the target solution and considered whether children's capacity for tool innovation might be better than previously thought.

In Chapter 3, I wondered whether children at the lower end of the testing age range could be supported to innovate tools. Four- and five- year-olds attempted the Hooks task for themselves or directed an apparently naïve adult to success. Children were significantly more likely to generate the solution to the Hooks task when they were asked to direct an adult to retrieve the bucket, rather than physically doing the task themselves. Directing an adult did promote their tool innovation, since 40% passed in the experimental condition compared with zero success in the control. However, innovation remained a difficult problem for most children in this sample and individual differences in children's performance remain. In the next chapter, I looked at a potential characteristic which might underlie these differences.

In Chapter 4, I looked at whether individual differences in children's tool innovation might be related to their creativity, by examining their performance on tool innovation and divergent thinking tasks. Children completed four tasks in a fixed order: Circles Task, Hooks Task, Object Uses Task, Floating Ball Task. I did not find a relationship between children's divergent thinking and tool innovation on any of these measures and less than half of children were successful on the Hooks task. Unexpectedly, children performed near ceiling on the second measure of tool innovation: The Floating Ball Task. This task was always completed last by children. I highlighted the possibility that having already completed another innovation task (Hooks) and two tasks requiring fluent and creative thinking, children developed a problem solving or creative thinking mindset, which made the generation of the solution to this problem easier. How children's previous experience and mindset could affect their tool innovation was explored further in Chapters 5 and 6.

In Chapter 5, I explored whether encouraging abstract thinking improves children's tool innovation. Previous literature demonstrated that encouraging abstract thinking, via spatial distance priming, significantly improved children's creative performance (Liberman et al, 2012). First, in Experiment 6, I aimed to see if these findings could extend to tool-innovation.

Second, I included a measure of creativity to see if the original findings of Liberman et al (2012) would be replicated. In Experiment 6, all children first completed a priming phase where they were shown a series of images in a fixed order, either from the spatially near to the distant (Distancing) or in the reverse order (Proximity). Half of the children in each priming condition then completed the Hooks Task followed by the creativity task, and the other half of the sample completed the creativity task followed by the Hooks Task.

I did not replicate the original finding of Liberman et al (2012), 5- to 7- year-olds' performance on the creativity measure was not affected by the priming condition. Five- to six- year-olds' tool innovation was also unaffected by the priming condition, or the order of task presentation (whether they completed the creativity measure before or after the tool innovation measure). Six- to seven- year-olds were most likely to innovate a tool in the Distancing priming condition, when the Hooks task came after the creativity task. They were least likely to innovate a tool when the Hooks task followed on directly from Proximity priming. The only significant difference observed was between those children in the Proximity HC condition and the Distancing CH condition, although the absolute numbers of successful innovators in the remaining conditions were very similar.

In Experiment 7, I focused on establishing if there is a direct relationship between spatial distance priming and tool innovation. Children completed the Hooks Task following one of three priming phases: Distancing priming, Proximity priming or a Baseline (same spatial images but in a randomised order). Children in the Distancing condition were significantly more successful at innovating a tool than children in both the Proximity and Baseline conditions. Spatial priming, from the proximal to the increasingly distal, improved children's subsequent tool innovation. I also noted children's poor performance in the Baseline condition, when compared with both the Distancing and Proximity conditions. I suggested that the unpredictable order in which the pictures were presented in the Baseline condition might been a negative experience for children and had a detrimental effect on their innovation performance. In the final experiment in Chapter 5, I investigated this possibility further.

In Experiment 8, I explored whether children's experience of predictability in the priming phase affected their tool innovation. Children completed one of three priming phases before progressing to the Hooks task. One third of children first completed spatial Distancing priming, which due to the increasingly distant images might have felt somewhat 'predictable' for children. Another third of children saw a series of images that were unrelated to spatial priming but that might have also felt somewhat 'predictable' in nature, as they all belonged to the same category – animals. The remaining third of children saw a series of images that were not obviously related to each other and as such might have felt somewhat 'unpredictable'. I found no significant difference between conditions. Further studies are required to unpick the findings from this final chapter further.

The effect of priming an analogical problem-solving mindset was investigated in Chapter 6, Experiment 9. Children who engaged in analogical problem-solving were significantly more likely to innovate the solution to the Hooks task, than those children who listened to and recalled stories involving problem-solving or stories unrelated to problem-solving. Innovation was improved despite their being no prior analogous stories or problems relating to the Hooks task. The findings suggested that priming an analogical problem-solving mindset might facilitate children's tool innovation and suggestions for follow-up studies are discussed later in this concluding chapter.

7.3 Discussion of Findings

7.3.1 Supporting Children's Tool Innovation

Young children's potential for tool innovation might be better than was previously thought. This thesis has shed light on some of the conditions under which children's tool innovation might be facilitated and has provided useful insights into possible future directions of research. I will now draw out some of the key findings from this thesis, make links between them and discuss them in relation to the wider literature and future research directions.

7.3.1.1 Reducing Demands

Research suggests that tasks with very specific goals, as is the case with the Hooks task, impose a high cognitive load (Wirth, Kunsting, & Leutner, 2009). This is because individuals are required to analyze the current state, target state and the means to reach to the target state (Newell & Simon, 1972). Keeping in mind these different aspects, updating them and also processing metacognitive knowledge, which is activated, results in a high cognitive load (Seufert, 2018). It has also been suggested that the ill-structured nature of the Hooks task makes it difficult for children, due to the missing information about how to transform from the start to the goal state (Cutting et al, 2011). The first experiments in this study explored how reducing task demands might affect children's performance on the Hooks task.

In the first two chapters of this thesis, we saw that children's performance on the Hooks task was improved when, among other things, the demands of the task were reduced. In the series of experiments in Chapter 2, children were given experience of a premade target tool. When they could use the tool on the task apparatus before attempting the Hooks task for themselves, 4- to 7-year-olds were significantly more likely to innovate a hook. The older children in the sample also benefited from seeing a target tool before having to innovate one to solve the task. These experiments gave children prior experience with the required solution which reduced task demands, since they no longer had to bring to mind the ideal tool for themselves. As well as reducing the demands of the task, allowing children to use or see a premade target tool provides them with information about how to solve the task.

These findings are in support of Cutting and colleagues' (2011) suggestion that children struggle with tool innovation problems such as the Hooks task due to their ill-structured nature. By providing children with information about the solution, either by allowing them to use or see a premade hook, before they attempted the innovation phase, I also made the task less 'ill-structured'. In Chapter 3 I was interested to see whether young children could solve the Hooks task without being given any clues about the solution required.

Children were significantly better at innovating the solution to the Hooks task when they were required to direct an adult rather than solve the task for themselves in Experiment 4. This reduced the demands of the task by removing the element of the task which physically required children to manufacture a tool. However, it did not provide children with any information about the solution. The findings suggested that some young children can innovate tool solutions. Although the majority of 4- and 5- year-old children were still unable to innovate the solution, performance was significantly better than baseline and these results offer a promising starting point for future research.

Although the Hooks task procedures were different across the experiments in Chapter 2 and 3, the common finding was that children were better at innovating tools when the demands of the task were reduced. In Chapter 2 this meant experience with premade hooks and in Chapter 3 this meant verbalising how to solve the task, rather than doing it oneself. Further investigation is needed to see how reducing or changing the demands of the task, without giving hints about the solution, might facilitate innovation. One way in which this could be investigated is to segment the task. The Hooks task could be broken down, with scaffolding from an experimenter, before children need to physically produce the solution. For example, children could be shown the apparatus and presented with the problem. Children could then be asked what they might need to get the bucket out. They could then be given the materials for making a tool. Next, the experimenter could ask them to explain or think about how they would solve the task before allowing them to attempt it. This would also shed light on whether asking children to produce explanations of how to solve the Hooks task is beneficial to innovation. By breaking down the task, rather than presenting the problem and materials in parallel, this might reduce the demands placed on the child all at once in standard versions of the Hooks task. Segmenting the task would also offer children more time to generate the solution which, given research suggesting children's tool innovation performance is improved with more time (Voigt et al, 2019), would also be worthwhile.

7.3.1.2 Priming

7.3.1.2.1 Abstract Thinking

In Chapters 5 and 6, I investigated an alternative way to support children's innovation, that would not require adapting the task or giving children any information about how to solve the Hooks task. Rather than reduce the demands of the task, I explored how priming activities could influence innovation. I found that children's tool innovation was better following different priming activities. In Chapter 5, children who completed spatial distance priming, and thus were encouraged to do more abstract thinking, were subsequently better at innovating than children who saw the spatial priming images in reverse or in a random order.

That priming abstract thinking, via spatial distance priming, facilitated children's propensity for tool innovation is an intriguing finding. It suggests that generating the solution to the Hooks task might rely, at least in part, on abstract, creative thinking. It also suggests that children can be primed to engage in this type of thinking and by doing so are subsequently more likely to innovate a tool. In Chapter 5, I found that divergent thinking was not predictive of children’s tool innovation. However, this sheds light on an alternative relationship between creativity and innovation: that innovation is more likely when children are engaged in abstract thinking. It is also encouraging that via a simple priming procedure, we might be able to observe significant improvements in innovative problem solving. Future research might investigate whether other types of psychological distance, e.g. temporal, hypotheticality, can similarly facilitate children’s innovation.

The raw data in Experiment 6, suggested that the creativity task might have also promoted innovation for some children. The absolute numbers of children who innovated a hook in the Distancing conditions and the Proximity condition where the creativity task preceded the Hooks task were very similar. In the next experiment I chose to focus on spatial priming, but the possibility that completing a creativity task prior to innovation might also facilitate performance is worth pursuing.

In Chapter 4, Experiment 5, divergent thinking was not predictive of innovation. However, I was surprised to find that children’s performance on another measure of tool innovation, the Floating Ball Task, was near ceiling. This task was always given to children last, having already completed two measures of divergent thinking and the Hooks task. It is possible that completing measures of divergent thinking and/or innovative problem solving before that task had a facilitative effect on innovation, by priming creative, abstract thinking. Future research may wish to follow up this finding and some suggestions are made later in this General Discussion.

7.3.1.2.2 Analogical Problem-Solving

Children were significantly more likely to solve the Hooks task when they had previously been engaging in analogical problem solving in Chapter 6. This was despite there being no problems or solutions analogous to the Hooks task during the priming phase.

Children received no clues about the solution to the Hooks task and yet, we saw significantly better innovation performance by children in this condition compared to both other experimental conditions (problem-solving stories and control stories). This was another example of how children's performance on the Hooks task appears to be sensitive to their experiences which come immediately before it. The finding also supports the idea that previous studies may not have been optimal for eliciting innovation and provides a useful suggestion to how we might be able to promote children's innovation.

I argued that one possibility for children's improved innovation in the analogical problem-solving condition is that children had formed a mindset to look for analogous solutions to physical problems during the priming phase, which facilitated them bringing to mind the solution for the Hooks task. The extent to which I can conclude that analogical problem-solving was responsible for children's improved tool innovation is limited and warrants further investigations. To unpick the findings from my final empirical chapter was unfortunately beyond the scope of this thesis, but I will offer suggestions of how future research could begin to do this in more detail, later in this General Discussion. In Experiment 9, children either completed the analogical problem-solving condition, the problem-solving stories condition or the control stories condition. In the problem-solving stories condition, although children heard examples of characters solving physical problems, they did not have to a) draw analogies or b) do physical problem-solving or c) do analogical problem-solving. It is therefore not clear what aspect of the priming phase was particularly beneficial for children in the analogical problem-solving condition.

A final possibility is that the analogical problem-solving condition gave children in that condition more opportunity to experience success than children in the other conditions. In the two other conditions, children were asked to listen to and recall stories. In the analogical problem-solving condition, as well as listening to stories children had to draw analogies between them and then complete transfer problems. During the priming phase, children were scaffolded where necessary to draw the analogies and solve the transfer problems (although all but one child on each problem solved these transfer problems independently). This opportunity to experience success before attempting the Hooks task may have improved children's mood and/or motivation and made them feel more confident, which had a knock-on effect to their performance in the Hooks task (n.b mood and problem-solving is discussed in more detail in the Future Research section of this chapter). The effect of a positive experience which involves experiencing success, before attempting novel, difficult tool problems such as the Hooks task, should also be explored.

Although the experiments across Chapters 5 and 6 were investigating seemingly different constructs and how they might relate to innovation, both suggest that children's innovation might be sensitive to the experiences which occur before they attempt the task. In addition, they demonstrate how children can be supported to innovate tools without needing to be given about the task itself. Simple priming procedures which, for example, prime abstract thinking or analogical problem-solving might stimulate children to be in a mindset which is more conducive to tool innovation.

7.3.2 Is children's innovation related to personal characteristics?

Individual differences in children's personal characteristics, such as their personality traits, cognitive abilities and motivational preferences, might underlie innovation. This is an underdeveloped area of research, with so far only two studies devoted to identifying personal characteristics of children's innovative problem-solving (Beck et al, 2016). This thesis explored how one personal characteristic, divergent thinking, might be relate to children's tool innovation. I found no evidence to suggest that individual differences in children's tool innovation can be explained by individual differences in their divergent thinking ability.

Individual differences in children's executive functions have also failed to explain differences in innovation ability (Beck et al, 2016). Thus far, only receptive vocabulary, as measured by the BPVS, has successfully predicted children's innovation (Beck et al, 2016). It is unlikely that this relationship is because of language demands of the task, since the task is predominantly non-verbal. One possibility is that the BPVS serves as an indicator of general intelligence (see Beck et al, 2009) and that it is this which underlies innovation. To date, these are the only experiments which have sought to identify traits which might be associated with child innovators. Although unsuccessful, it would perhaps be premature to rule out that differences in children's personal characteristics might underlie tool innovation performance.

An area of research which looks at individual differences between how children perceive intelligence and their goal-oriented behaviour, so called 'growth- and fixed-mindset' (Dweck, 2006), might shed light on the pattern of performance we see on the Hooks task in early-middle childhood.

7.3.3 Is the Hooks task just difficult?

Whilst I hope that this thesis has provided some useful information about children's tool innovation and how it might be promoted, one limitation of this thesis is its narrow focus on the Hooks task. By using the same task to measure children's tool innovation, which is also the most frequently used tool innovation task in the wider developmental literature, I hoped to be able to see clearly which experimental conditions facilitated innovative problem solving. However, future research should seek to test children's tool innovation on a range of different tasks to ensure that children's performance on the Hooks task is representative of their overall tool innovation ability and not just their ability to make hooks.

Several times in this thesis, consistent with existing literature, I have found that children younger than 7 years find the standard version of the Hooks task, difficult. One possibility is that this task is especially difficult for children. This is supported by recent findings that children are better at tool innovation tasks when they are given more time and when they could solve the problem using manufacturing methods *other than needing to reshape a material* (Voigt et al, 2019). Voigt and colleagues (2019) intended to see if children were better tool innovators when they are given more time and have the option of making a tool using a number of manufacturing methods. Children were required to push/pull a toy from a vertical/horizontal tube by innovating an appropriate tool. There were different ways a child could make a tool using different materials, depending upon the experimental condition. For example, in one condition they could fit together two pieces of wood, one of which had a hook at the end, to make a long enough hook to pull out the bucket. In another condition, they needed to remove a cardboard collar from a metal rod with a hook at one end, in order to make the tool narrow enough to fit into the tube. They found that for some modes of tool innovation, such as adding together two pieces of plastic tubing to make a long enough straight tool, children didn't succeed until the 10^{th} minute of allotted time. However, the authors found that children who were required to reshape a material into a hook to solve the problem still showed poor rates of innovation, even when they were given 10 minutes to complete the task. Reshaping of a material to make a tool was the most difficult.

Additional evidence that the Hooks task might be an especially difficult example of a tool innovation task for children has been demonstrated in this thesis. When children completed another measure of tool innovation (Floating Ball Task) in Experiment 5, their performance was near ceiling. Although, children's superior performance on the Floating Ball Task compared with the Hooks task could be seen as evidence that the Hooks task is especially difficult, it is worth noting that these findings were in contrast with the existing literature involving that task (e.g. Hanus et al 2011; Ebel et al, 2019). Previously, children have shown similar levels of success on the Hooks task and Floating Peanut Task. Children's improved performance on the Floating Ball Task could be explained by the conditions which preceded testing. In Experiment 5, children completed the task at the end of a battery of other tasks involving divergent, creative thinking and problem solving. It is possible we saw improved performance as a result of this prior experience, which warrants further investigation. However, it is also possible that performance on the Floating Ball task was improved because of differences in the way this version of the task was set up compared to the Hanus version. This is discussed in Chapter 4.

It could be argued that the transfer problems in Experiment 9, were also measures of tool innovation. The Floating Ball Task and the Combining Task required children to innovate a tool to solve a physical problem. On both of these tasks, all but one child successfully innovated the correct tool. However, children attempted these tasks having already listened to stories which contained analogous problems and solutions. Therefore, it is not appropriate to compare children's performance on those measures in this thesis to their performance on the Hooks task. Evidence from the wider literature suggests that analogical problem-solving is likely to have supported innovation. On two problems similar to the Combining Task, children had to add together two pieces of dowel to a) make a long hook to solve the Hooks task or b) a long tool to push a pom-pom out of a horizontal tube (Cutting et al, 2014). Less than a third of children aged 4- to 7- were successful, which replicates the low levels of innovation observed on the Hooks task. In order to make comparisons about the relative difficulty of the Hooks task, Combining Task and Floating Ball Task, children ought to attempt these tasks in a counterbalanced order, with no prior experience of analogous problems or solutions in the task context.

Children's performance on the Hooks task is better under certain conditions and can be supported. For example, 4- and 5- year-olds are more likely to innovate the solution to the task when they are asked to direct an adult to solve the task, rather than doing it for themselves. Children also benefit significantly from using a premade tool on the task, before being required to innovate a tool of their own. Innovation is also improved when children have been primed to engage in abstract thinking or have been engaging in analogical problem-solving. Together these findings suggest that standard versions of the Hooks task might not be optimal for capturing the true extent of children’s capacity for innovation and that children’s performance is sensitive to the experiences which precede the task.

The extent to which we can make overarching conclusions about children’s tool innovation from the results of one measure, the Hooks task, is limited. Research investigating children’s tool innovation in the future might consider how children perform on a range of innovation tasks, which involve a variety of manufacturing methods and not only reshaping of a material. By understanding the relative strengths and weaknesses of children’s tool innovation, we can build a more complete picture of how this ability develops and can be supported.

7.4 Theoretical Implications of This Thesis

To date tool innovation has been identified as a difficult and late-developing ability in childhood (Cutting et al, 2011). It has been thought that children’s difficulty with solving the Hooks task lies in their ability to bring to mind the solution for themselves. This is supported by the relative success children had on the Hooks task in Chapter 2, when they had the opportunity to use/see a premade hook. These results also suggested that it might be a specific difficulty with bringing to mind the solution (i.e. needing a hook), rather than a difficulty with knowing how to manufacture an appropriate tool, that underlies poor performance on the Hooks task in early childhood. However, this thesis has also provided evidence that children can bring to mind the solution to the Hooks task from a younger age than has been observed to date.

This thesis has demonstrated that previous studies investigating children's tool innovation have underestimated their true potential. Children can bring to mind the solution to the Hooks task for themselves from an earlier age. For example, in Chapter 3, 4- and 5-year-olds were significantly more likely to solve the Hooks task when they were required to direct an adult to solve the task. Further, in Chapter 5 children were more successful when they completed spatial distance priming prior to the Hooks task. Finally, in Chapter 6 children were significantly more likely to innovate the solution to the Hooks task after they had been engaging in analogical problem solving involving other physical problems. Although these studies imply that there might be different ways in which innovation can be facilitated, they commonly imply that tool innovation may not be an all-or-nothing ability and challenge the notion that young children are poor innovators.

First, perhaps tool innovation is not an all-or-nothing ability. Research has sought to identify the characteristics of child innovators (e.g. Beck et al, 2016). In Chapter 4 of this thesis, divergent thinking was not predictive of tool innovation. The evidence increasingly suggests that it is unlikely that tool innovation is a stand-alone ability but rather is multi-faceted and relies on several, related abilities. It is difficult to imagine that tool innovation can be entirely dissociated from other cognitive abilities such as creativity, divergent thinking, analogical reasoning and inhibitory control, to name a few. I posit that this is why the pursuit of identifying a *single* personal characteristic which might predict children's innovation ability has thus far been unsuccessful (Beck et al, 2016). I argue that whilst the identifying characteristics of innovators could be useful, an alternative to understanding innovation in children is understanding the ways in which it can be supported, in order to gain insight into what processes might underlie innovation.

To date, research has focused on whether or not children can innovate the solution to the Hooks task and at what age they can reliably do so (e.g. Beck et al, 2011). This thesis took an alternative approach that focused on whether and how children can be supported to innovate. In taking this approach, it has become clear that although tool innovation remains a difficult problem for some young children, many are more capable of innovation than previously thought, when the circumstances are optimal for them to do so. That not all types of support are equal for children, is also telling about children's tool innovation. For example, seeing a premade tool was helpful for some children but not all (Chapter 2). Engaging in analogical problem-solving had a facilitative effect on innovation for the majority of children, but not all (Chapter 6). Spatial priming had a facilitative effect on innovation but again, did not make innovation trivially easy for all children (Chapter 5). Directing an adult to solve the task made innovation significantly more likely for 4- to 5- year-olds but it remained difficult for the majority of children (Chapter 3). Together, these results suggest that individual children might require different input to facilitate or 'fill the gaps' in their knowledge/skills to innovate. Thus, not all information is equally useful to all children. This would explain patterns of results where some information is useful to some children and not others (e.g. seeing a premade tool, using a tool, directing an adult etc.) and may reflect individual differences in children's knowledge and abilities. As such, children require varying levels and types of scaffolding to innovate tools to solve problems. It may be the case that the ability to innovate tools is present at a younger age than previously thought, but external factors then influence the likelihood that children will display innovative behaviour.

7.5 Future Research

Throughout this thesis I have touched on possible directions for future research. One of the key findings from this thesis is that children's tool innovation can be supported through their pre-test experiences, often without needing to give children any information about the solution to the problem. This has implications for our understanding of children's capacity for innovation, but also wider implications in an educational context, where facilitating innovative and creative problem-solving is important.

Future research could explore how children's prior experience with tools relates to their tool innovation. The technical reasoning theory of human tool use (Osiurak, Jarry & Le Gall, 2010) proposes that human tool use relies upon the ability to engage in technical reasoning. Technical reasoning is based upon 'technical laws' which are derived from our knowledge and experience of interacting with the world. Taking account of this hypothesis, we could predict that children with a greater experience of interacting with objects including tools and craft materials, might also be better tool innovators, since they have acquired more technical knowledge. This could be manipulated experimentally, by giving some children the opportunity to use a variety of craft materials and tools in other contexts prior to innovation. For example, using hooks in other contexts such as a game of Hook-a-Duck and using pipecleaners to make springs. If those children who have more experience of tools are better at innovation, we might infer that innovation relies on sufficient domain knowledge and experience of tools.

Following on from my finding that young children were more innovative when they were directing an adult to solve the Hooks task, future research could investigate whether producing explanations was the dominant factor in facilitating innovation. Explanation improves problem solving by giving children the opportunity to articulate their knowledge, which in turn draws their attention to gaps in their current knowledge. Busch, Willard and Legare (2018) suggest that explanation works alongside other discovery-oriented behaviours like exploration and asking questions, which stimulates causal learning and in turn improves problem solving. A useful follow-up from Experiment 4 would be to investigate whether having to produce an explanation of how to solve the task is what improved young children's innovation. Children could be asked to explain how they would solve the Hooks task: before attempting the task for themselves, whilst they attempt to solve the task themselves, or to an adult who has to solve the task. A control group who are not asked to produce any explanation would also be useful. This would give an insight into how producing explanations might facilitate innovative problem-solving and whether the element of directing an adult supports innovation beyond producing explanations of one's own actions or planned action.

The effect of priming abstract thinking was investigated in Chapter 5. It was found that priming spatial distance facilitated Hooks performance. However, in Experiment 6, examination of the raw data suggested that creativity task, which sometimes came between the spatial priming and tool innovation measure, could also have had a facilitative effect on performance. This was not explored further within this thesis but provides an opportunity for further investigation. In Experiment 8, no differences were observed between spatial priming and priming which involved children looking at a series of pictures of animals or a series of unrelated objects. One possibility is that all of these conditions primed abstract thinking. Future studies could explore whether spatial priming specifically supports tool innovation or whether other ways of priming abstract thinking, for example by giving children creativity tasks like the Circles task or TACT, also supports innovation.

Another possibility which could account for a number of the findings in this thesis is that experiences which facilitate positive mood promote children's subsequent tool innovation, or those which induce negative mood hinder innovation. For example, children's poor Hooks task performance in Experiment 7, when the spatial images in the priming phase were presented in a randomised order, might be explained by the consequence it had on children's mood. Children may have experienced uncertainty or unfamiliarity when the images were presented in an unpredictable order, which could have also made some of the pictures more unfamiliar as they were out of context. The resultant negative mood could have hindered children's subsequent innovation. On the other hand, the pictures which were presented in a predictable order in the spatial condition and the familiar pictures in the animal / unrelated pictures may have induced a positive mood for children. Likewise, the experience of successfully solving problems in the analogical problem-solving condition in Experiment 9 could have enhanced children's mood and facilitated innovation. Evidence from the mood literature suggests that positive mood improves creative problem solving (Isen, Daubman, Nowicki (1987). Positive mood, induced by watching a short comedy film or being given a bag of sweets, improved performance on two creative tasks: Duncker's (1945) candle task and M.T, Mednick, S.A. Mednick & E.V.Mednick's (1964) Remote Associates Test. The effect of mood manipulations on children's tool innovation is worth future consideration.

An alternative way in which we might seek to support tool innovation is by promoting a growth-mindset. A simple way of exploring this idea would be to use a priming procedure, where children listen to statements that: emphasize that intelligence is the result of effort and is changeable, construe challenges as opportunities for growth and learning and encourage persistence in the face of difficulty. For example: "When we find something tricky, it's important not to give up and to keep trying", "When we practice, we get better at things", "Sometimes we have to get things wrong so that we can learn how to get them right" etc. This could be compared with a control group who hear other, positive statements about things that are unrelated to mindset, such as fun facts, and a baseline group who attempt the task with no priming phase. Children could then complete a tool innovation task, such as the Hooks task. If fostering a growth-mindset can promote innovation performance, we might expect children in the growth-mindset priming condition to outperform those in the other conditions.

Research on growth-mindset has also highlighted the importance of the type of praise that children receive in relation to how they are motivated to approach tasks and their performance. Praising ability, in this case intelligence, rather than effort has been demonstrated to affect children's motivation and performance (Mueller & Dweck, 1998). Children who were praised for intelligence were more likely to go on to rate intelligence as something fixed and unchangeable, whilst those praised for effort were more likely to rate it as increasable. In addition, children praised for intelligence rather than effort reported less enjoyment of the task and were more likely to blame their failures on a lack of ability rather than a lack of effort. Sensitivity to praise has been show in studies with younger children. Preschool children who were given process-focused praise e.g. "You did a good job drawing" were more persistent on the task and showed more positive self-assessments than those who were given person-focused praise e.g. "You are a good drawer" (Cimpian, Arce, Markman & Dweck, 2007).

Findings such as these demonstrate that the types of praise children receive can change their beliefs about the malleability of traits such as intelligence, which then influences how they respond to challenges and perform on tasks. Praise focused on the individual and their ability lead children toward a fixed- mindset on the malleability of traits, whilst praising the process or an individual's effort might lead to a growth-mindset. Therefore, we might consider the type of praise and prompts we give children whilst engaging with tool innovation problems such as the Hooks task. Rather than focusing praise at the end of the task, we might praise children whilst they are doing the task, praise their effort and encourage persistence. For example: “I can see you are trying really hard”, “Well done, keep trying”, “It is ok to try something new when one thing doesn’t work out right”. It might also be worth highlighting before the task begins that children will be rewarded for their effort, rather than whether they successfully retrieve the bucket. For example, “Don’t worry if you can’t manage to get the bucket out, I am giving prizes to the children who try their best/ don’t give up/try out different ideas.” It is possible that giving children process-focused praise could enhance their motivation to persist with difficult tool innovation problems and ultimately facilitate performance.

7.6 Conclusions

This thesis has explored young children’s capacity for tool innovation, with a particular focus on the conditions which might facilitate it. Although tool innovation remains difficult for many young children, the findings in this thesis suggest that our previous understanding of children’s tool innovation has underestimated their ability. A majority of the youngest children in our sample (4-year-olds) could innovate a tool having previously had the chance to use a premade target tool, and a significant minority could innovate the solution when they were directing an adult to solve the task. Other ways in which I suggest children’s tool innovation was supported include priming analogical problem-solving and abstract thinking. As well as shedding light on some of the ways in which children’s tool innovation can be supported, this thesis has provided useful insights into possible directions for future research.

The complexity of human technology is what sets us apart from other non-human animal species and is undoubtedly responsible for our development as a species. Tool innovation is important for human evolution and, in an increasingly technology-centred world, this most important aspect of human cognition deserves the increasing focus of research it is receiving. Current research has focused on children's difficulty with innovation and understanding the limitations on children's ability. Taking a different approach, in this thesis I have explored how children's innovative problem-solving might be encouraged. It is important that future research takes note of children's sensitivity to their pre-test experiences and how they can impact children's performance on novel physical problems such as the Hooks task. In order to build a complete picture of the developmental trajectory of tool innovation, we must first have an accurate understanding of children's capacity for innovation across childhood. This will shed light on the potential developmental mechanisms which underlie innovation, but also enable us to support young children to be innovative, creative problem solvers which could have far reaching consequences on their academic achievement and, longer-term, their career options.

Appendices

Appendix 1

The stories used in the priming phase of Experiment 9 are shown below.

Story Set A

<u>The Thirsty Bird</u>

Once upon a time there was a bird who lived in a forest. She was pretty and clever. Some of her friends often told her about the people, buildings and other things in the city. One day, sin the summer, she decided to go to the city. She got up before the morning and flew for several hours, miles and miles, because the city was far away. It was very hot. She became very thirsty but could not find anything to drink. Finally, she landed in a field and found a bottle half full of water. She put her beak into the bottle and stretched her neck, but the water was too low in the bottle for her to reach it. After thinking a bit, she came up with a good idea: she picked up a pebble in her beaks and dropped it in the bottle. Then she picked up another and another. She continued to put pebbles into the bottle, one by one, and each time a pebble fell in the bottle, the water got a little bit higher, until finally she could reach the water with her beak and got a long, cool drink. Refreshed after drinking the water she sang and flapped her wings, and flew on to see the city.

<u>Fallen Ball</u>

Sarah was in Year 1. She liked gymnastics, horse-riding and playing ping-pong. Sarah was very good at these things. One day she was playing a game of ping-pong in the back garden with her sister, Poppy. Sarah and Poppy were having a lovely time playing together. Suddenly, the ball bounced across the lawn and rolled into a small but deep hole. The hole was too deep for the girls to reach the ball with their hands. They had to think of a different way to get the ball out After a few minutes of thinking, she connected the hose to a water tap and filled the hole with water from the hose. The girls were very happy because the ping-pong ball floated to the top. After getting the ball, they went on playing the game.

Story Set B

The Hungry Monkey

Once upon a tie there was a monkey who lived in a beautiful forest with his friends. He was very clever and worked hard. He and his friends had a little house and planted many flowers around their home. Every day, they walked several miles looking for food. One day, he and his two friends were caught by some hunters and were sent to the zoo. From then on, he had to live in a big cage. He was always very hungry in the zoo. He often tried to get food outside of his cage or from other cages. One day, people put some bananas outside the cage, but they were too far away for him to reach. He looked around and saw two poles lying right outside his cage. He picked up one of the poles and tried to reach the bananas with it. However, the pole was too short. He was very hungry indeed. After thinking a bit, he came up with a good idea: He grabbed both poles and stuck two together by putting one inside the other o make a pole long enough to reach the bananas. He finally got the food and was very proud.

Caught Ball

Eddie was in Year 2. He liked to swim, play football and cricket, and go fishing with his grandfather. Eddie was good at these things. One day, during the Summer holidays, he was playing cricket in the back garden of his house. Eddie and his friends had much fun together. Now it was time for Eddie to bat. When the ball was bowled, Eddie hit it. Up, up, went the ball to the top of the roof of the house, and it got stuck in a corner. The boys could not reach the ball and could not find a ladder to climb on top of the roof, either. They had to think of a different way to get the ball down. They thought and thought. Finally, Eddie came up with a great idea. He combined two bats together with a thick string so that the bats were long enough to reach the ball. The boys were happy. After getting the ball, they went on playing their game.

Control Stories: Unrelated to problem-solving

<u>The New House</u>

Nancy was moving into a new house. It was white, with red windows. It was much bigger than her old house. She was going to have her very own room. Before, she had to share with her big sister. On moving day, the movers carried the beds and chairs and rugs out of the old house and into the lorry. When everything was in the lorry, they closed it up, and drove to the new house. Nancy and her family got into their car and also drove to the new house. As soon as the door was unlocked, Nancy ran into the new rooms. She found the kitchen, and the bathroom, but she didn't stop until she found her very own bedroom. There she sat, waiting for the movers to bring her things. "I will put them where I want," she thought. "My sister can't tell me what to do in my very own room." Nancy was sure to be happy in this new house.

<u>The Zoo Visit</u>

Jennifer and her grandparents were going to the zoo. They parked in the big car park, and then rode in a fancy trolley to the gate. They bought tickets and gave them to the gatekeeper. Now they were inside. "Where do you want to go first'?" asked Grandma and Grandpa. Jennifer told them that she always like to go to the elephants first because they were closest. They watched the elephants, and then there was a big noise from the seals, so they went over there, and watched the keeper throw them fish. Watching the seals eat made them hungry, so Grandma and Grandpa and Jennifer ate lunch, too. Then they looked at the monkeys and the hippo and the giraffe, and so many other animals that they all got too tired to walk anymore.

They rode the trolley back to their car. On the way home Jennifer fell asleep and dreamed of a fun new animal- a mix of a giraffe and a bear

Appendix 2

In Experiment 9, Analogical Problem-Solving Condition, children were scored for their level of recall. Below are the scoring criteria with examples (taken from Chen & Daehler, 1989).

Level 1 Irrelevant Recall

(I) Recall: "A monkey.., once lived in the forest. He found some food . . . The zookeeper caught him in the forest. He got put in the zoo, and he was always hungry."

(2) Comparison: (Experimenter: "Do you think the two stories are alike'?") "No. Well the boy was not an animal . . ."

(3) Comparison: "They were alike because some of them are kind of funny. Maybe one of them is a make-believe story and one of them is a real story."

Level 2 Incomplete Recall

(1) Recall: "That he lived in the forest with his friends. He planted many flowers... Some hunters came and then caught him and brought him to the zoo... He put two poles together and got the banana."

(2) Comparison: (similar to that in Level 1)

Level 3 Complete Specific Recall

(1) Recall: "He was very hungry, but the banana was too far away. He could not reach the banana. He got two short poles. He found an idea. He put two poles together to reach the banana."

(2) Comparison: (similar to that in Level 1 or 2)

Level 4 Abstract Representation

(1) Recall: (similar to that in Level 3)

(2) Comparison: "Yes . . . In the monkey story, the monkey put two poles together, and in the other story, the boys were playing baseball, they put two bats together, and it was longer, to get the ball down... The two stories are alike."

(3) Comparison: "Yes, because both of them could not reach something... They thought for a few minutes. They both put two things together to reach something…and got what they were looking for."

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