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PAPER

Personality predicts innovation and social learning in children: Implications for cultural evolution

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Abstract

Innovation and social learning are the pillars of cultural evolution, allowing cultural behaviours to cumulatively advance over generations. Yet, little is known about individual differences in the use of social and asocial information. We examined whether personality influenced 7-11-year-old children's (N = 282) propensity to elect to observe others first or independently generate solutions to novel problems. Conscientiousness was associated with electing for no demonstrations, while agreeableness was associated with opting for demonstrations. For children receiving demonstrations, openness to experience consistently predicted deviation from observed methods. Children who opted for no demonstrations were also more likely than those opting for demonstrations to exhibit tool manufacture on an innovation challenge and displayed higher creativity, as measured by an alternate uses task. These results highlight how new cultural traditions emerge, establish and advance by identifying which individuals generate new cultural variants in populations and which are influential in the diffusion of these variants, and help reduce the apparent tension within the 'ratchet' of cumulative culture.

KEYWORDS
cultural evolution, imitation, individual differences, innovation, personality

1 | INTRODUCTION

The cultural diversity of humans is unparalleled across the animal kingdom; diversity that is maintained through a combination of innovation and social learning (Boyd & Richerson, 1985). Innovation enables adaption to new environmental challenges, as well as modifications or improvements of existing cultural repertoires – a process termed cumulative culture (Tennie et al., 2009). High fidelity social learning (termed here imitation) affords faithful transmission of such innovations, promoting population-specific technology and skillsets. Imitation and innovation are thus fundamental to human culture (Legare & Nielsen, 2015). Understanding how new cultures (group-specific behaviours acquired through social transmission) emerge, establish and advance has become a multi-disciplinary focus for, among others, psychology, zoology, anthropology, archaeology and biology. Yet, while there is much evidence of variation in social learning strategies influencing when individuals choose to learn socially and whom they learn from (Kendal et al., 2018), we have very little knowledge of which individuals are more likely to copy others and which are more likely to innovate Further, cultural evolution theory suggests that the ratcheting (Tennie et al., 2009) process of cumulative culture requires both innovation by modification (socially-mediated innovation) and high fidelity copying to retain traits until beneficial innovations occur. Yet the apparent tension in the inter- and intra-individual interaction between these two processes, and how they contribute to cumulative culture, is still poorly understood (Kendal et al., 2018).

RESEARCH HIGHLIGHTS

- Personality predicts 7-11-year-old children's overt learning strategy choices when faced with novel puzzleboxes.
- Children rated high in agreeableness elect for demonstrations, children rated high in conscientiousness elected for no demonstrations.
- Children rated high in openness to experience were more likely to deviate from observed demonstrations.
- Older children, and males, were more likely to elect for no demonstrations.
- Learning strategy choices are associated with tool innovation and creativity performance.

Understanding whether there are individual-level characteristics distinguishing learning strategy used (defined here as the relative used of asocial or social learning) would provide crucial insights regarding how new cultures emerge (through asocial inventive innovators – those that asocially generate new cultural behaviours, Carr et al., 2016), establish (through social learners) and cumulatively advance (through both modifying innovators and social learners, Carr et al., 2016).

Children are key conduits of cultural transmission (Legare, 2019). The complexity of our cultural repertoires means children regularly need to solve new problems through social learning (information acquired from others), innovation (generating a new, useful, and potentially transmitted learned behavior), arising from asocial learning or a combination of both (innovation by modification). Each strategy has associated costs and benefits: social learning facilitates rapid, low-cost attainment of culture-specific skills, behaviour and conventions (Over & Carpenter, 2012) but can be unreliable or outdated, whereas asocial learning promotes direct and reliable information acquisition but can be a risky and time-consuming process (Kendal et al., 2009). Children are prolific social learners, capable of acquiring and maintaining complex information from others (Price et al., 2017), and show an attraction to social information from birth (Meltzoff & Moore, 1989). Conversely, individually (asocially) innovating solutions to experimentally induced problems is extremely difficult for children. Studies presenting children with tool-based innovation challenges indicate that most young (under 8 or 9 years) children fail such tasks (Beck et al., 2011; Rawlings & Legare, 2021). Given this, it is perhaps unsurprising that when offered the choice, the majority of young children will overtly elect to copy another over attempting to solve novel problems asocially (Flynn et al., 2016). However it remains unclear which individual factors differentiate the minority that are willing to tackle novel problems asocially (and innovate) from the majority that prefers to use social information, and from those who combine asocial and social information (Mesoudi, 2017; Rawlings et al., 2017).

To examine individual differences in learning strategy use, we presented 7-11-year-old children with a puzzle box containing a reward that could be removed in multiple ways (Multi-Method Box, MMB (Carr et al., 2015), Figure 1) and offered participants the choice of social demonstrations by an adult or to 'go it alone' without demonstrations (Flynn et al., 2016). This age range was chosen to expand upon the age range used in previous studies (4-9-years-old; Carr et al., 2015; 3 and 5- years; Flynn et al., 2016), and because this age range has received less attention in studies of social learning and innovation than younger children. Previous work using these experimental paradigms indicates that 4-9-year-old children generally remain faithful to observed MMB solutions, even when they are inefficacious, but that older children are more likely to engage in innovation by modification and deviate from demonstrations (Carr et al., 2015). Additionally, most 3-5-year old children will elect for demonstrations over no demonstrations on (different) novel puzzzleboxes (Flynn et al., 2016). Thus, children have a strong proclivity to use social information when it is available, but with increasing age are more willing to attempt solutions through individual learning. Here, we combined these paradigms to ask whether individual differences predicted 7-11-year-old children's propensity to use social or asocial information when solving novel puzzzleboxes.

To assess whether personality ratings were linked to whether children overtly elected for social information or not, and subsequent performance on the MMB, we collected parental (and teacher) ratings of children's personality using the five-factor model ('Big Five') using a fully validated measure (Asendorpf & van Aken, 2003) (see Supplementary file SI1.3). The Big Five personality traits comprise agreeableness (being kind, prosocial, trusting and empathetic), conscientiousness (being orderly, planful and diligent), extraversion (being social, assertive, and active) openness to experience (being exploratory, curious, inventive and creative) and neuroticism (being worrisome, fearful and temperamental). Extraversion positively correlates with copying others in infants' (Hilbrink et al., 2013), as does negative affect (Yu & Kushnir, 2020). Extraversion also predicts young children's judgment of others as reliable sources of information (Canfield et al., 2015), perhaps because extraverted individuals are more attracted to social stimuli than introverted individuals (Feiler & Kleinbaum, 2015) while children lower in negative affect may experience positive emotions when imitation others (Yu & Kushnir, 2020). In contrast, openness to experience is consistently linked with innovation and creativity in adults (Chamorro-Premuzic & Reichenbacher, 2008), particularly in business settings (Baer, 2012; Rawlings et al., 2017), ostensibly because openness to experience encompasses being creative, curious and inventive; characteristics that lend themselves to innovation.

Here, we assessed the predictive power of multiple personality traits in determining whether children overtly elected for social information, through observing demonstrations, or not when faced with a novel puzzlebox. As well as the MMB, children completed a standard tool-use innovation challenge known to be difficult for children (the hook task, Beck et al., 2011) and a divergent thinking task (Guilford, 1967). These additional tasks allowed investigation of whether there were differences in the ability to independently manufacture appropriate tools (the hook task) and generate novel ideas (divergent thinking), between children who elect to solve a puzzle-box asocially and those who opt for social information first. While previous work has shown that executive functions and divergent thinking do

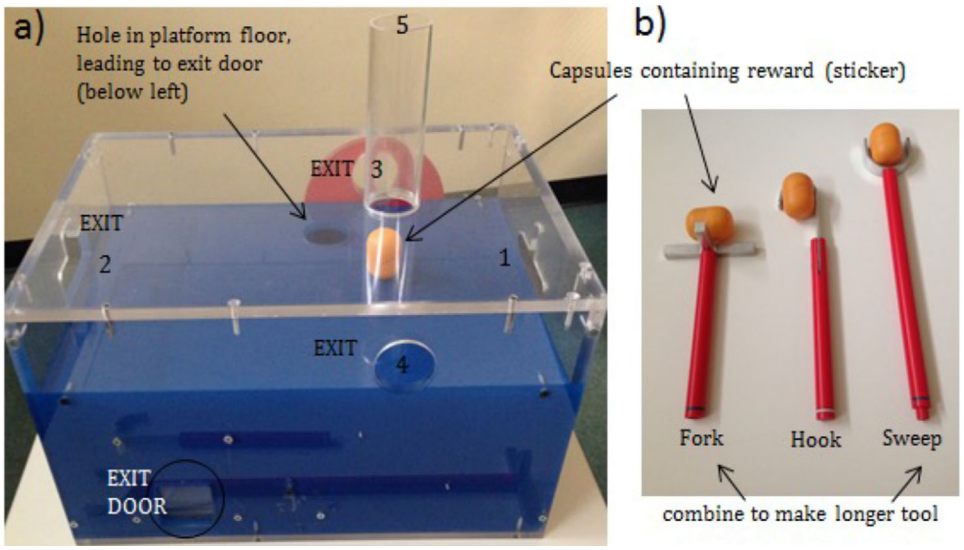

FIGURE 1 The multi-methods box. A puzzle-box offering multiple ways of extracting sticker rewards contained within capsules (a), and the three tools available (b)

not predict children's asocial innovation (as measured by hook task performance, Beck et al., 2016), here we additionally assessed the relationship between individual differences and children's overt choice of social information or not.

Drawing on the research above, we had four main predictions. First, most children would elect for demonstrations over no demonstrations (Flynn et al., 2016). Second, personality would predict children's MMB learning strategies. Specifically, extraversion would predict children's propensity to request to copy a demonstrator (Hilbrink et al., 2013) and openness to experience would predict children's propensity to elect for no demonstrations (Rawlings et al., 2017). Third, we predicted that openness to experience would positively predict tool innovation on the hook task and divergent thinking performance (McCrae, 1987). Fourth, drawing on research showing that by 5 years, children who elect to solve novel puzzles asocially, versus those that elect for demonstrations, showed greater success at these tasks than those that elected for demonstrations (Flynn et al., 2016), we predicted children who elected to solve the puzzle-box asocially would outperform those who opted for social information on the hook and divergent thinking tasks (we acknowledge predictions 2 and 3 likely overlap). Based on previous work suggesting age and sex differences (Carr et al., 2015; Cross et al., 2017) in the propensity to use social information, these were controlled for in all analyses (i.e., on all tasks).

2 | METHODS

2.1 | Participants

Two hundred and eighty-two 7- to 11-year-old children (M = 9.41 years, SD = 1.17; 136 males) participated. Children were recruited from primary schools mainly in a working-middle class area in the Northeast of the UK. Participants came from four different school years: Year 3 (7-8-years-old, N = 65), Year 4 (8-9-years-old, N = 79), Year 5 (9-10-years old, N = 71) and Year 6 (10-11-years old, N = 67). Although individual-level ethnicity data was not collected, the ethnic composition of the recruitment area is 94.8% Caucasian, 0.73% mixed race, 1.88% Asian and 0.49% black and 2.54% other. This study was approved by the Department of Anthropology at Durham University ethical committee.

2.2 | Battery of tasks

2.2.1 | Personality instrument

Personality was measured by asking parents to complete an abbreviated version of the California Child Q-Set (Lorr & Block, 1964) an instrument that measured the Big Five personality traits (agreeableness, conscientiousness, extraversion, openness to experience and neuroticism) in children. The abbreviated version, created by Asendorpf and Van Aken (Asendorpf & van Aken, 2003), is a 24-item questionnaire, comprising statements with which the parents/guardian indicate how characteristic they are of their child on a five-point Likert scale. An example statement is 'I see my child as someone who is helpful and cooperative', where the parent would indicate whether they disagreed strongly (1) ranging to agreeing strongly (5). For analyses, mean scores for each of the five personality traits were calculated.

The Big Five personality factors have been successfully validated using this instrument (Asendorpf & van Aken, 2003), and it has been shown to correlate with children's long-term behaviour and school achievement (Asendorpf & van Aken, 2003; Dennissen et al., 2007). Personality questionnaires were distributed to parents and subsequently collected from parents by schoolteachers. For validity purposes, for 51% (N = 144) of participants' teachers were also asked to complete the abbreviated CCQ.

2.2.2 | Experimental tasks

Children were presented with three tasks: the multi-method puzzlebox (MMB), the hook task and the divergent thinking task. Participants were tested individually, away from other classmates. Upon arrival, an experimenter introduced himself and explained that he was going to play some games and obtained verbal consent for participation from the children, before administering the battery of tasks. To negate any potential task order effects, the order of task presentation was randomised across participants using the RAND function in Excel. All task interactions were video recorded with a camcorder (Sony Handycam) discretely placed in the room.

2.2.3 | Puzzlebox

The MMB (Carr et al., 2015) was presented to children (see Figure 1a). The overall aim of the MMB was for children to retrieve novel sticker rewards contained within 10 small egg-shaped capsules (one at a time). The MMB comprised two levels separated by an opaque floor. The top level contained an entry chute to bait the task with the reward capsule, along with four other potential entry and exit points to obtain the reward. One of the entrance points required turning a red dial to gain access. Participants could retrieve the reward by using one of three plastic tools (hook, sweep and fork, Figure 1b) to manipulate the capsule through the entrance/exit points (holes) at the upper level and retrieve it. The specific tools only fitted into certain access points (entrances) and were long enough only to reach (and manipulate) the capsule from certain access points. The sweep and fork tools could be combined to create a tool with a longer reach. In addition to the entrance/exit holes on the side of the box, there was a hole in the opaque floor (exit hole in Figure 1a). If participants manipulated the capsule to this hole it dropped to a lower opaque level of the MMB via a hidden slope where it remained behind a blue door to be retrieved by the experimenter who then added a sticker to the participant's sticker pile.

To reduce experimenter and any potential model biases participants were told that the box belonged to a friend (Carr et al., 2015). Given children typically assume adults are prestigious demonstrators (Wood et al., 2012), this approach (i.e. that the demonstrator was not the *perfect* model) allowed investigation of individual differences in learning strategy use in a context in which children may be motivated to innovate. Following this and a brief explanation of goal of the task (see Supplementary file SI 1.2 for details), the experimenter said, "Would you like to have a go yourself or would you like me to have a go first?". If the participant elected for a demonstration, s/he received a social demonstration, and if s/he elected to have a go her/himself, they received no social information. This phrasing was chosen to match that of Flynn et al. (2016), in which children of a similar demographic were effectively selective in their learning strategy choice. By early to middle childhood children develop metacognition of their ability to solve problems and the need to acquire help (Annevirta & Vauras, 2006), and are known to interpret adults' actions as informative and instructional (Csibra & Gergely, 2011; Heyes, 2016) particularly formal school settings (Paradise & Rogoff, 2009). Thus, in the context in which testing was conducted it was likely to be implicit that an adult going first would provide useful information.

For social demonstrations, the experimenter demonstrated a single predetermined technique four times, where the fork tool was inserted via a specific entrance point (entrance one in Figure 1a) and the capsule was manipulated into the hole in the opaque floor (exit in Figure 1a). Only one of the four demonstrations (25% in total) was successful, which was achieved by using a discrete wireless remote control that locked/unlocked the exit door at the lower level, so the reward could/could not be obtained. Given that previous work (Carr et al., 2015) has shown that even in the face of repeated unsuccessful adult demonstrations on the MMB children remain faithful to witnessed methods, and assign prestige to adults in puzzlebox solving contexts (Carr et al., 2015; Wood et al., 2012), a low efficacy demonstration rate (25%) was used to encourage subsequent exploration in participants and to impart that innovation may be profitable. All social demonstrations were delivered to all participants in the same order, where the final attempt was successful after three unsuccessful attempts. After the social demonstration (if applicable), participants were told, 'Now it's your turn to have 10 goes to get the eggs out and you can make a sticker pile with the ones you get out. You can do anything you like'. To match the social information, the exit door remained locked for participants' first three attempts, regardless of success or methods used, and was opened using the remote control for the fourth attempt, and remained so thereafter (Carr et al., 2015). Those who elected for no social demonstrations were told "You can have 10 goes to get the eggs out and can make a sticker pile with the ones you get out. You can do anything you like". Over 10 subsequent attempts, participants could use any one of three tools, any one of five entrance points and any one of four exit points to extract the reward. Additionally, two of the tools could be combined for longer reach.

An attempt was defined as when a participant inserted a tool into the MMB with the seeming purposeful intention (regardless of success or not) of making contact with the capsule and ended when the tool was removed (Carr et al., 2015). Purposeful intention was deemed as when a participant's gaze and head orientation was directed towards the task while interacting with the tools in an attempt to retrieve the capsule. There were some cases involving multiple actions, which were counted as one attempt. If, for example, a participant used a tool to push the capsule towards an exit with one tool, with the intention of making it easier to extract from a different entrance point with a different tool, this was considered as part of the same attempt. If participants failed to retrieve the reward after an attempt, the experimenter removed and reset the capsule (whilst the participant was distracted), such that all children received 10 'turns'. There was no time limit given to participants, and at the end of the task, all children exchanged their sticker pile for a large sticker.

2.2.4 | MMB coding

All video recordings of attempts were coded to score the methods used and success/failure to retrieve a reward. To emulate the coding and analyses system developed by Carr and colleagues, who assessed children's learning strategies using the MMB (Carr et al., 2015), the following MMB behaviours were coded (and subsequently analysed):

All participants

- Whether participants elected for social demonstrations or not (0 coded as elected for demonstrations, 1 coded as no demonstrations).
- The number of failed attempts (max. 10).
- The number of different tools used across all attempts (max. 4).
- The number of different entrances used across all attempts (max. 5).
- The number of different exits used across all attempts (max. 6).

Children who elected for demonstrations only

- The number imitations across all attempts; matching one or more of the same tool, entrance and exit as the demonstration (max. 30).
- The number of exit innovations across all attempts; where a different exit than the demonstration was used (max. 10).
- The number of tool innovations across all attempts; where a different tool than the demonstration was used (max. 10).
- The number of entrance innovations across all attempts; where a different entrance than the demonstration was used (max. 10).

Children who did not elect for demonstrations only

- The number of different tools used across all attempts.
- The number of different entrances used across all attempts.
- The number of different exits used across all attempts.
- The number of repetitions; the total number of times, across all attempts, that an individual repeated a previously used method exactly (max. 9).

This coding rubric was selected because exit innovations were the sole way to enhance the efficacy of success, and thus separating exit from entrances and tool innovations allowed examination of whether children innovated in a way that improved efficacy or whether they were deviating in ways that provided no benefits over witnessed methods (Carr et al., 2015).

2.2.5 | The hook task

The hook task is a tool innovation challenge known to be difficult for young children (Rawlings & Legare 2021). Participants were presented with a transparent tube containing an out-of-reach small bucket holding a sticker. Participants were provided with a straight pipe cleaner and a 15-centimetre (cm) piece of string (a distractor item). To extract the sticker, participants were required to manipulate the pipe cleaner into a hook shape and lift the bucket, by its handle, out of the tube.

Upon presentation of the hook task, the experimenter said "Can you see the sticker inside of this tube? I want you to see if you can get it out". Participants were given 3 min to solve the task, and there were no further instructions provided during testing. Successful attempts (retrieving the reward) were scored as 1, and failures as 0, and the time to succeed was recorded. If participants failed to extract the sticker after 3 min, a score of 180 s was given. As previous work has shown that around 8 years most children succeed with this task (Beck et al., 2011), the specific technique used to retrieve the sticker was also of interest and thus recorded. For instance, previous work has shown that children can extract the sticker reward without modifying the pipecleaner (i.e. tool use; Beck et al., 2014), although forming a hook shape is more efficient (i.e. tool innovation). All children received a sticker irrespective of success or failure.

2.2.6 | Divergent thinking

The measure of divergent thinking was an alternate uses test (Guilford, 1967), requiring the participant to list potential uses for an everyday object. Participants were presented with a paperclip and the experimenter said "Here is a paperclip. I want you to think of and tell me all the things a paperclip can be used for, all the things you can do with a paperclip". These instructions were chosen, rather than to explicitly instruct children to think creatively, to comply with typical administering of divergent thinking tasks (Runco et al., 2005). To facilitate creative performance (Said-Metwaly et al., 2019), no time limit was given for responses. The task ended when children stated and confirmed that they could not think of any more uses for the paperclip. Responses had to be deemed suitable to be scored. For example, an answer of 'bending' would not qualify unless a more detailed description was provided (i.e., what the paperclip could be bent into).

Scores of fluency and originality were calculated. Fluency simply denotes the total number of different responses given. Originality reflects the rarity of responses compared to other participants' responses. For originality, responses given by 2–5% of participants were scored one point and responses given by 1% or less were assigned two points. Responses given by over 5% of participants were scored 0 (Said-Metwaly et al., 2019).

3 | RESULTS

We start by presenting children's preference for demonstrations or not on the MMB and the factors predicting the learning strategies children adopted (hypotheses 1 and 2). We then present children's performance on the hook and divergent thinking tasks (hypothesis 3), and finish with an investigation of the relationship between performance on these tasks and children's MMB learning strategies (hypothesis 4). To control for alpha inflation arising from multiple comparisons we used a false discovery rate control (Storey, 2002), set at 10%, as recommended by McDonald (2009), which calculates the expected proportion of false positives (erroneous rejection of null hypotheses) from the discoveries (see Supplementary file SI2 for further details and full details of the statistical tests).

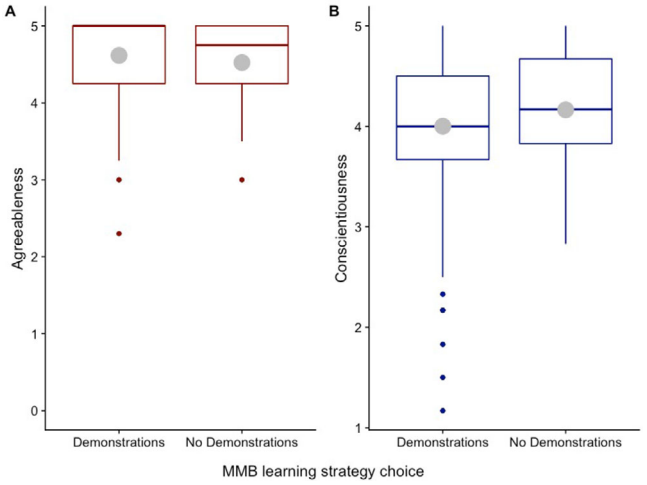

FIGURE 2 *Boxplots of parental ratings of agreeableness (A) and conscientiousness (B) for children who elected for demonstrations and no demonstrations on the MMB task. Horizontal lines within boxes represent median personality ratings and grey circles denote mean personality ratings*

3.1 | Children's preference for demonstrations and no demonstrations

Hypothesis 1. *We hypothesized that most children would elect for demonstrations over no demonstrations* (Flynn et al., 2016).

As predicted, overall, most 61% (N = 173) of children elected for social demonstrations and 39% (N = 109) elected to solve the MMB asocially without demonstrations. Females (71%, N = 103) were more likely to elect for demonstrations than males (51%, N = 70; Odds Ratio (OR) = .45, CI: .26-.76, Wald = 9.01, p = .003) and younger children (Mean, M = 9.27 years, standard deviation, SD = 1.18) were more likely to elect for demonstrations than older children (M = 9.63, SD = 1.13), OR = 1.29, CI: 1.03-1.61, Wald = 4.84, p = .028).

3.2 | Did personality predict performance on the MMB, hook and divergent thinking tasks?

3.2.1 | MMB

Hypothesis 2. We predicted extraversion would predict children's propensity to request to copy a demonstrator (Hilbrink et al., 2013) and openness to experience would predict children's propensity elect for no demonstrations (Rawlings et al., 2017).

When controlling for age and sex, children rated as more agreeable were more likely to elect for social demonstrations (N = 173, OR = .55, CI: .32-.96, Wald = 4.38, p = .036), whereas those rated as more conscientiousness were more likely to opt for no demonstrations (N = 109, OR = 1.79, CI: 1.06-3.04, Wald = 4.67, p = .031, Figure 2). Both of these findings were not predicted. None of the other Big Five personality traits were predictive of initial learning strategies, contrary to our prediction.

Within children who elected for social demonstrations, innovations (departures from the demonstrated method) increased with age, both for exit innovations (M = 0.89, SD = 1.97, beta = .58, p < .001, CI: .43-.73) and entrance innovations (M = 2.50, SD = 2.54, beta = .12, p = .006, CI: .03-.20), suggesting older children were more likely to display innovation by modification. Moreover, as predicted, those children rated higher in openness to experience were more likely to deviate from the demonstrated methods than those lower in openness (exit innovations: beta = .94, p < .001, CI: .54-1.34; entrance innovations: beta = .94, p = .003, CI: .14-50), and fewer imitative actions (replicating any form of the demonstrated technique, M = 19.57, SD = 6.55, beta = -.08, p = .012, CI: -.15–.02). Children rated high, compared to low, in conscientiousness were less likely to deviate from the demonstrated method (exhibiting fewer exit innovations: beta = -.397, p = .009, CI: -.70–.10), whereas those rated higher in agreeableness (beta = .42, p = .026, CI: .05-.79) and neuroticism (beta = .27, p = .013, CI: .06-.48) were more likely to exhibit exit innovations than those low in agreeableness and neuroticism, respectively (Table 1). Against predictions, extraversion had no influence on children's copying propensity.

For children who elected for no demonstration, neither age, sex, nor personality influenced performance on the MMB.

3.3 | Did age predict personality ratings?

Although we controlled for age (and sex) in the above analyses, to further examine the possibility that age was driving the results, we conducted additional analyses examining whether age was a predictor variable of each of the personality factors. Of most relevance here are conscientiousness, agreeableness and openness as they were key predictors of children's learning strategies: conscientiousness was associated with electing for no demonstrations, agreeableness was associated with electing for demonstrations and openness to experience was associated with deviating from demonstrations. Results showed that age was not significantly associated with agreeableness or openness, suggesting no relationship between these traits and age. Further, age was significantly negatively associated with conscientiousness (p = .003) such that older children were rated as less conscientious. Thus, although age and conscientiousness were significantly positively associated with electing for no demonstrations, with age children were rated as less conscientiousness, indicating that age was not driving MMB learning strategies. For completeness, age was significantly positively associated with extraversion (p = .001) but not with neuroticism.

3.4 | Hook task; overall performance and individual differences

Hypothesis 3. *We predicted that openness to experience would positively predict tool innovation on the hook task.*

TABLE 1 Overview of significant findings across tasks by personality traits

Social Information Use (MMB)				Innovation by modification (MMB)				Innovation by Invention			Creativity (Divergent thinking)	
LS: demonstrations	Imitations	Fewer exit innovations	Fewer entrance innovations	Fewer tool innovations	Fewer imitations	More exit innovations	More entrance innovations	More tool innovations	MMB LS: No demonstrations	Hook task: Success	Hook task: Method	Fluency	Originality
					Openness							Openness	Openness
Agreeableness						Agreeableness							
						Neuroticism							Neuroticism
		Conscientiousness							Conscientiousness				
													Extraversion

LS, learning strategy.

Altogether, 82% ($N = 230$) of participants succeeded in retrieving the sticker reward with the pipe cleaner, and 18% ($N = 52$) failed. Children showed identical rates of success on the hook task regardless of their choice for a social demonstration or not, with the MMB (social demonstration: 82%, $N = 141$; no demonstration: 82%, $N = 89$). There were two main techniques to retrieve the reward; 1) 55% of participants ($N = 156$) manipulated the pipe cleaner into a hook shape to retrieve the bucket by its handle, and 2) 22% of participants ($N = 61$) used the straight pipe cleaner to push the bucket against the side of the apparatus and drag it within reach. This 'drag' technique has been observed in other studies but counted as unsuccessful (Beck et al., 2014; Sheridan et al., 2016). We included it here as it allows us to differentiate between tool use and tool innovation (Beck et al., 2014). 5% of participants ($N = 13$) used a different technique, such as manipulating the pipe cleaner into a 'pincer' shape or tying the available string to the pipe cleaner and fishing the sticker out (for analysis of the efficiency of each technique as measured by time to success, see Supplementary file SI 3.5). These rare techniques were pooled together and classed as 'alternative technique' (for analyses of the efficiency of hook task methods, as measured by time, see Supplementary file SI3.4). Age was a significant predictor of the technique used ($X^2 = 22.79$, $p < .001$), but sex was not. Age positively predicted the propensity to use the hook technique compared to the dragging technique (OR = .51, Wald = 17.48, $p < .001$, CI: .375-.701), and compared to failing (OR = .63, Wald = 9.09, $p = .003$, CI: .46-.85), suggesting older children were more likely to manipulate the pipe cleaner to create a tool, whilst younger children were more likely to attempt to use the pipe cleaner in its original state or to fail to retrieve the reward. Contrary to our prediction, controlling for age and sex, personality did not predict children's performance on the hook task, neither in terms of success nor specific method used (all $ps > .05$).

3.5 | Divergent thinking; overall performance and individual differences

Hypothesis 3. *We predicted that openness to experience would positively predict divergent thinking* (McCrae, 1987).

Overall, children named a mean of 4.94 ($SD = 3.06$) different uses for a paperclip (fluency) and an originality (rarer responses) mean of 4.07 ($SD = 5.74$). Older children exhibited higher divergent thinking fluency (beta = .06, $p = .015$, CI: .01-.11) and originality (beta = .096, $p < .001$, CI: .04-.15) than younger children. Males (beta = .22, $p = .001$, CI: .09-.34) also provided more original responses for a paperclip than females.

As predicted, controlling for age and sex, children rated high in openness to experience scored higher on fluency (beta = .13, $p = .020$, CI: .02-.25) and originality (beta = .22, $p < .001$, CI: .09-.35). Children rated as higher in neuroticism (beta = .12, $p = .005$, CI: .04-.20) and extraversion (beta = .18, $p = .001$, CI: .07-.29) showed high originality scores (Table 1), which was not predicted. No other tests were significant, and there was no relationship between performance on the hook and divergent thinking tasks ($ps > .05$).

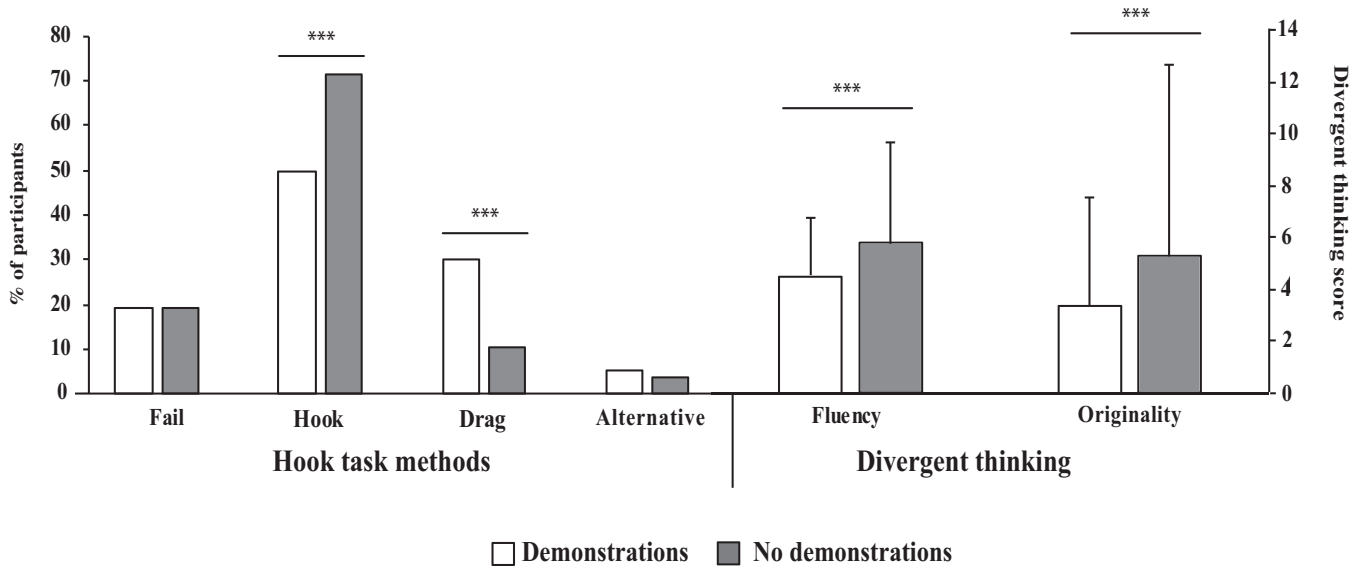

FIGURE 3 The percentage of participants who used each technique on the hook task (left) and mean divergent thinking scores (right), by MMB learning strategy choice

3.6 | Did MMB learning strategy choice predict hook task and divergent thinking performance?

Hypothesis 4. *We predicted children who elected to solve the puzzlebox asocially would outperform those who opted for social information on the hook and divergent thinking tasks.*

3.7 | Hook task

As predicted, controlling for age and sex, children who opted to attempt the MMB task asocially without demonstrations were more likely to use the hook method compared to those that opted for a social demonstration, who were more likely to use the rarer dragging technique (OR of using the hook method = 3.72, Wald = 11.02, $p = .001$, CI: 1.53-.22, Figure 3). No other effects reached significance (all $ps > .05$). Thus, children who opted to solve a novel puzzlebox without demonstrations were more likely to show tool *manufacture* while those opting for demonstrations were more likely to show tool *use*.

3.8 | Divergent thinking

As predicted, controlling for age and sex, children who elected for no initial demonstration ($M = 5.74$, $SD = 3.93$) with the MMB named more overall uses for a paperclip than those who elected for a demonstration (fluency, $M = 4.44$, $SD = 2.23$; beta = −.21, $p < .001$, CI: −.32–.09). Likewise, as also predicted, those electing for no MMB demonstrations named more unique uses ($M = 5.21$, $SD = 7.42$) than those who elected for demonstrations (originality, $M = 3.35$, $SD = 4.22$; beta = −.34, $p < .001$, CI: −.46–.22), Figure 3. Thus, compared to children who opted for a social demonstration, children who elected to solve a novel puzzlebox asocially showed higher creativity scores. For full details on hook task and divergent thinking performance, see Supplementary file SI3.3.

4 | DISCUSSION

The vast diversity, complexity and cumulative nature of human culture is based on a combination of innovation and social learning. Here, we show that intrinsic individual differences predict children's use of specific learning strategies in an experimentally induced context. We also show, for the first time, a direct link between children's overt learning strategy choice and tool innovation and creativity performance. While replication is needed, these findings provide a novel contribution to the field of cultural evolution by potentially indicating which children generate new behavioural innovations into populations and which are key to the social diffusion of these innovations.

4.1 | Did personality predict children's learning strategies?

Our key findings were that when controlling for age and sex, children rated as high in conscientiousness were more likely to elect for no demonstrations, while children rated highly in agreeableness were more likely to elect for social demonstrations. Of those that elected for demonstrations, children rated higher in openness to experience consistently showed a greater tendency to deviate from observed methods (innovation-by-modification).

Agreeableness denotes the tendency to be prosocial, trusting, and cooperative (Freitag & Bauer, 2015; Mooradian et al., 2006); traits that lend themselves to electing for social information (demonstrations)

over asocial information (no demonstrations). More agreeable children may have elected for demonstrations to establish a positive relationship with the demonstrator (Schleihauf et al., 2018). Since children copy others for affiliative motives (Schleihauf et al., 2018), and being imitated induces positive affect towards the 'imitators' (Chartrand & Bargh, 1999) it is possible that the more agreeable children elected for social information to establish a positive relationship with the demonstrator, as well as being more trusting of them.

Alternatively, it is conceivable that agreeable children elected for demonstrations out of politeness, or deference to an adult experimenter. Although this is possible, there is little suggestion within the literature deference to others is associated with children's agreeableness. Further, previous work using this experimental paradigm has shown that children's learning strategy choices reflect individual differences in effective use of learning strategies (Flynn et al., 2016), suggesting children were selective in their choice of learning strategies, rather than electing for demonstrations out of deference. Electing to copy others may thus serve a "social glue" function for social learning, by allowing children to learn new skills and form relationships and affiliate with others (Legare & Nielsen, 2015; Nielsen, 2018; Over, 2020), including from adults (Flynn et al., 2016; Wood et al., 2016) a process which may be facilitated by agreeableness.

In contrast, conscientiousness, characterised by being industrious, organised and achievement-striving is strongly correlated with performance in academic (Poropat, 2014) and non-academic (Scher & Osterman, 2002) settings. Conscientiousness is also linked with increased self-efficacy (the belief in one's own ability, Lee & Klein, 2002). Given low task-related confidence is a contributing factor in the propensity to conform to social information (Cross et al., 2017; Morgan et al., 2012) this increased self-efficacy, perhaps resulting from high achievement in other domains, may explain the relationship between conscientiousness and the propensity to tackle the MMB without demonstrations when given the choice.

Within those who elected for demonstrations, however, children rated as more agreeable produced more exit innovations, and conscientiousness was a negative predictor of exit innovations. The exits were the only feature of the MMB critical to success, and as such exit innovations (compared to entrance or tool innovations) represented the only way to improve reward-retrieval efficacy (Carr et al., 2015). While counterintuitive to children's overt learning strategy choices, these findings highlight that the combination of personality traits, and the context in which learning occurs, also play an important role in children's learning strategies. For instance, while conscientiousness is linked with self-efficacy (Lee & Klein, 2002), it is also linked with low creativity (Chamorro-Premuzic, 2006), and this relationship is exacerbated when being closely monitored (George & Zhou, 2001). Children who are highly agreeable (electing for demonstrations) and highly conscientious may be more likely to defer to observed methods, particularly in experimental settings when researchers are present. There is also some evidence that agreeableness is positively linked with 'everyday creativity' (Batey & Furnham, 2006). It is therefore also possible that when explicitly offered the opportunity to observe social demonstrations, those high in agreeableness will elect for social information, but when given further opportunities to interact with novel tasks display more creative tendencies.

Similarly, while children opting for demonstrations were generally reluctant to diverge from the demonstrated behaviour, those rated as high in openness to experience showed a heightened and consistent capacity to do so. Openness to experience is intrinsically linked with creativity (Rawlings et al., 2017) and here, children rated as high in openness also exhibited greater divergent thinking skills than those rated as lower in openness. The combination of agreeableness (electing for demonstrations) with openness (curiosity, inventiveness and tendency to explore) may allow such children to circumvent prepotent responses of copying the socially learned methods of the MMB (i.e. the method demonstrated by the experimenter), and to apply novel techniques, a process children find difficult (German & Defeyter, 2000). The consistency with which openness to experience was associated with innovation by modification is suggests this finding is robust and should be further investigated. Given that innovation by modification may occur more frequently than innovation by invention and is crucial to improving existing cultural repertoires (Carr et al., 2015, 2016 ; Henrich, 2015; Muthukrishna & Henrich, 2016), these findings shed important light on the ontogeny of cumulative culture.

Thus, in contrast to traditional studies, which directly impose social or asocial information upon participants, by allowing children to *overtly* decide whether they wanted to receive social information or not, we reveal new insights into the interaction between personality and the context in which learning strategies occur (Flynn et al., 2016). This includes—as previously noted—agreeableness and conscientiousness predicting opting for demonstrations and no demonstrations (innovation by invention, see Carr et al., 2016), respectively, yet once social information was acquired children higher in agreeableness showed greater innovation (by modification) while higher conscientiousness was associated with more faithful copying of the exit used. We encourage future research to replicate this intriguing result.

In contrast to previous studies (Rawlings et al., 2017), extraversion was not correlated with social information use. This may be because previous studies were based on temperament measures of personality (rather than the Big Five), with much younger children than the current study (1-3 years vs. 7–11 years here; see Supplementary file SI4.1 for more details about the differences between studies, and for information about other findings regarding extraversion and social information use).

4.2 | Age and sex differences in learning strategy use

Two important findings from our study were age and sex differences in learning strategy use. In line with previous work (Beck et al., 2011; Carr et al., 2015; Frick et al., 2017; Said-Metwaly et al., 2020) older children were consistently more likely to engage in innovative MMB behaviours (both in terms of innovation by invention and by modification), and outperformed younger children on the hook and divergent thinking tasks. Over childhood, children's ability to generate novel ideas, solve

innovation challenges, and to judge efficacy of observed behaviours rapidly improves. These developmental differences are likely a result of age-related maturation of a suite of cognitive processes supporting these capacities, which allow children to determine effective strategies by generating, assessing, updating, and switching between ideas and strategies when solving novel problems, as well as inhibit ineffective ones (Best & Miller, 2010; Buttelmann & Karbach, 2017; Carr et al., 2015; Rawlings & Legare, 2021).

Although, as with Flynn et al. (2016), most children elected for demonstrations, males were more likely than females to do so. While this was not predicted, there some evidence that females are more likely to use social information than males. Adult research has shown that females conform to others more than males (Bond & Smith, 1996). Task-specific confidence and task type (Cross et al., 2017; Morgan et al., 2012), as well as risk aversion (Brand et al., 2018), may be mediating factors in females' greater use of social information. Given that electing to 'go it alone' was a riskier strategy than electing for social demonstrations (as demonstrated by the lower success rate of those electing for no demonstrations), this finding may, in part, be explained by risk aversion. Moreover, males, in this study, also generated both more overall and more novel uses for a paperclip than females did. Thus, the males' comparatively greater willingness to bypass social information may be a function of their greater capacity for divergent thinking (see Supplementary file SI4.3 for further discussion on sex differences in social information use).

4.3 | Individual differences in cross-task performance

Children who elected for no demonstration on the MMB were more likely to display tool manufacture in response to an innovation challenge and outperformed those opting for social information on a divergent thinking task. The hook method (tool *modification*) ostensibly represents a more erudite (and efficient, as measured by time; see Supplementary file SI3.4) technique than the dragging technique (tool *use*), requiring a two-step process of imagining an appropriate tool type and physically manipulating the tool into the appropriate shape (Beck et al., 2012).

These results reveal a new, important, evidence-based link between children willing to bypass social information and innovative and creative performance, suggestive of cross-task consistency in asocial problem-solving performance for individuals with highly conscientious and open personality characteristics. Using social information initially appears a productive strategy, allowing children to quickly acquire task-appropriate information with a relatively low cognitive load. However, over time, children who are willing to tackle novel problems asocially acquire the cognitive resources (e.g., flexibility, creativity) to engage in successful innovation on new tasks. Our results also highlight the importance of assessing learning strategies across multiple tasks (for cross-task consistency in toddlers imitative learning, see Yu & Kushnir, 2020). Future work could assess cross-task consistency in other domains, such as conformity or measures of innovation on non-tool use tasks. For example, some children are known to conform to standard uses of tools and find it difficult to use them in nonconventional ways (termed functional fixedness; German & Defeyter, 2000). Thus, future research could assess whether children who are less likely to conform to social norms, for example, are more likely to engage in tool innovation.

However, given that those who elected for demonstrations witnessed the demonstrator fail on 75% of attempts, it is also important to consider whether motivation levels differed between demonstrations and non-demonstration groups. That is, although this efficacy rate was selected because previous work with the MMB has shown that even when witnessing very low demonstrator success rates remain faithful to the witnessed methods (Carr et al., 2015), it is possible that participants here who witnessed a demonstration may have had lower belief in their ability to succeed at retrieving the reward. Although research is scare – particularly regarding children and tool innovation – the research examining the relationship between motivation is equivocal (Steele et al., 2017). Thus, while reduced motivation may have contributed to the demonstration groups' lower propensity to generate novel solutions, further work is needed to explore this.

4.4 | Replication of previous work and future directions

Our study combined methodological approaches from two previous puzzlebox studies, allowing assessment of replication of their findings. First, as with Flynn et al. (2016), who found that 75% of 3-5-year-olds elected for demonstrations on novel puzzlebox tasks, we found that the majority of 7-11-year-olds (61%) did so. The slightly lower proportion of children here who elected for demonstrations is indicative of older children's greater propensity to solve problems asocially. Second, we found that older children were more likely to deviate from the demonstrated method, replicating findings by Carr et al. (2016), who used the MMB and the same demonstrated technique with 4-9-year-olds. We replicated previous work documenting age-related increases in the use of the hook method to retrieve the reward on the hook task (for a review, see Rawlings & Legare, 2021) and in divergent thinking (Said-Metwaly et al., 2020).

Our findings that individual differences (personality and divergent thinking) did not predict hook task success rates are also in line with those of Beck et al. (2016) who found no relationship between measures of executive functions and divergent thinking and hook task performance in 5-7-year-olds. However, our finding that divergent thinking was associated with children's propensity to elect to bypass social information and engage in innovation by invention further highlights the value of using multiple approaches to assess the different types of innovation.

There are several future lines of research which would validate the conclusions on how children's cultures emerge and establish. By offering children the explicit choice of demonstrations, our study provided novel insights into how personality correlates with children's overt learning strategy choices. However, it precludes comprehensive

assessment of whether children high or low on a given trait are more likely to exhibit different learning strategies within the initial choices. For instance, those who elected for demonstrations were rated as higher in agreeableness, meaning only highly agreeable children were examined for innovation by modification. In those who elected for no demonstration there was no relationship between agreeableness and the propensity to attempt different MMB solutions across their 10 attempts. Notwithstanding, it remains important for future research to measure the role of personality in innovation by modification in children who have not overtly elected for demonstrations.

Future work could examine whether these results replicate in different domains of social learning. Imitative fidelity is generally higher in conventional frameworks (i.e., social conventions and norms) than instrumental, as tested here, (Clegg & Legare, 2016a; Moraru et al., 2016). It would be interesting to examine whether traits such as agreeableness, conscientious and openness to experience predict the propensity to elect for social information or not, or to deviate from observations, respectively, in a conventional framework. Given that agreeableness denotes being prosocial, kind and affiliative, one might predict that the association between this trait – and other socially based ones such as extraversion – and social information use may be stronger in conventional than instrumental contexts.

An additional important next step is to replicate these findings in non-western cultures to document whether a preference for social information holds cross-culturally. There is increasing evidence that children display cultural variation in the expression of imitation and innovation (Berl & Hewlett, 2015; Clegg & Legare, 2016b; Neldner et al., 2019; Nielsen et al., 2014; Rawlings et al., 2019; Van Leeuwen et al., 2018), although the drivers of these differences remain unclear. Self-ratings on Big Five personality traits (Costa et al., 2001; Hofstede & McCrae, 2004), and attitudes to conformity (Clegg et al., 2017) differ across cultures, and assessing their relationship with learning strategies is key to understanding how individual and cultural factors interact to shape the ontogeny of cultural learning. Formal education, for example, is increasingly recognised as an important predictor of children's imitation and innovation (Lew-Levy et al., 2020; Neldner et al., 2017), and the globalisation of schooling provides a unique opportunity to assess its impact on learning strategies across cultures.

Finally, another key next step is to examine whether these findings hold in naturalistic, open diffusion settings, wherein one model learns a puzzlebox solution and groups members observe and subsequently interact with the apparatus. Assessing whether, for example, children high in agreeableness are those who seek social information, and those high in openness to experience are those who deviate from witnessed methods in group settings, would validate our conclusions regarding the generation and spread of cultures.

5 | CONCLUSION

Fundamental to cumulative cultural evolution is the interplay between imitation and innovation. Innovations generate, and introduce, new behaviours and skills to a populations' repertoire, which are then disseminated through social learning. Our findings shed new light on how, in experimental settings, children's cultural traditions may emerge and establish by allowing us to understand which individuals generate new cultural variants in populations—either innovation by invention (children rated as high in conscientiousness) or through innovation by modification of observed behaviours (children rated as high in agreeableness and openness to experience)—and those influential in the social diffusion of these variants (children rated as high in agreeableness and low in openness to experience). In turn, these findings, if robust to replication, may be applied to highlight and foster skills, such as innovation, from a young age, by providing insights into individual variation in its development.

Though this study used a large sample size, replications across multiple domains and populations as well as in open diffusion settings are required to assess the robustness of these findings. This study lays the platform for an exciting field of research into when and why these particular personality traits shape the learning strategies humans adopt, whether these findings extend into adolescence and adulthood, and the impact upon cultural evolution.

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ETHICAL APPROVAL AND CONSENT

Ethical approval for the collection of child data was approved by the Department of Anthropology Ethics Committee, Durham University, UK and all procedures aligned with ethics of the British Psychological Society. For all participants, parental/guardian consent was obtained at least 1 day prior to testing, and children gave verbal consent themselves immediately before testing. Parental/guardian consent forms and personality questionnaires were administered to schools, who distributed and received the forms and questionnaires to, and from, parents/guardians. Personality questionnaires were administered to teachers to rate a subset of participants.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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