When does it pay to follow the crowd? Children optimize imitation of causally-irrelevant actions performed by a majority

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1.1 Introduction

Humans are frequently cast as “over-imitators.” This claim, which has generated a burgeoning body of literature and attention in recent years, has followed numerous observations that both adults and children, across diverse cultures, frequently blanket copy even actions that are perceivably irrelevant to achieving an instrumental end goal (see Hoehl et al., 2019, for a review). This phenomenon, which has not been observed in other species (Clay & Tennie, 2018), has led to claims that human copying is often surprisingly unselective (Chudek et al., 2016; Whiten et al., 2009), and susceptible to inefficiencies (Lyons et al., 2007).

At odds with the notion of humans as ‘over-imitators’ is an alternate body of literature showing that humans are rational, selective, and flexible imitators (see Kendal et al., 2018, and Schleihauf & Hoehl, 2020, for reviews). For example, even 1-year-old infants can adjust their imitative fidelity in response to the goals and capabilities of the demonstrator (e.g., Carpenter et al., 1998; Carpenter et al., 2005; Gergely et al., 2002), and 2- to 6-year-old children imitate selectively depending on the social situation they find themselves in (e.g., Clegg & Legare, 2016; Herrmann et al., 2013; Over & Carpenter, 2009; Watson-Jones et al., 2016; Yu & Kushnir, 2014). Indeed, cumulative culture, a hallmark of human behavior, is expected to require a fine and flexible balance between high-fidelity copying on the one hand, to provide a basis upon which improvements can be made, and selective copying on the other, to facilitate the innovation of new ideas and modifications (e.g., Legare & Nielsen, 2015).

Cultural evolutionary theory posits that human cultural complexity is also underpinned by evolved social learning biases that guide selective, adaptive, and flexible social transmission (Boyd & Richerson, 1985; Laland, 2004). Growing lines of evidence, from both experimental and more naturalistic contexts, support the idea of selective and flexible social learning biases in humans (Kendal et al., 2018; Wood et al., 2013a). One such social learning bias that has received particular attention, and which is regarded as key to the reliable, efficient, and accurate transmission of social information, is majority-biased copying (Boyd & Richerson, 1985). The majority bias, it is argued, is a good heuristic for judging a behavior's value: Behaviors exhibited by the majority of individuals likely reflect higher pay-offs. Majority-biased copying acts as a stabilizing force, synchronizing and maintaining high-value behavior at the population level.

Yet while a default bias to copy the majority should typically result in the acquisition of efficient and effective behavior, it should not be so inflexible that new and more efficient behavioral variants cannot emerge and become established (Eriksson et al., 2007). Indeed, Wilks et al. (2015) have shown that even children do not blindly follow the crowd. In this study, children aged 4-5 years were more likely to copy the majority when the majority and minority both performed different causally-relevant solutions. However, if the majority's solution failed, children copied the minority. Similarly, Bernard et al. (2015) found that, by 6 years of age, children endorsed object labels provided by a reliable dissenter over an unreliable group, and Kim and Spelke (2020) found that 4-year-olds were more likely to endorse information from a minority who had seen what was inside a container over a majority who had not.

These previous studies present a relatively blunt test of the flexibility of majority-biased copying, because some of the actions the demonstrators performed in them were unsuccessful. In contrast, Evans et al. (2018), taking a cultural evolutionary approach, found that majority-biased copying in children does not extend to majorities who perform causally-irrelevant actions. Although the 4- and 6-year-old children in their study copied irrelevant actions at high levels when the demonstration was unanimous, it only required one, minority individual from a group of demonstrators to omit the irrelevant action to see "over-imitation" plummet, and majority-biased copying lost. This, they surmised, was indicative of a highly flexible and specialized integration of social learning strategies, which allows us to home in on the most relevant actions in instrumental tasks, preventing inefficient or potentially costly actions from evolving to stability in real-world, instrumental contexts. They thus concluded that children might more accurately be cast as broadly "optimal-" rather than "over-" imitators (see also Hoehl et al., 2019, and Keupp et al., 2013, for the growing consensus that it is time to reject the term "over-imitation").

However, the context in which Evans et al. (2018) advanced that children are more accurately cast as "optimal imitators" was limited in that it only addressed majority-biased copying of irrelevant actions in instrumental learning contexts. Not all real-world learning is as driven by instrumental end goals, and there could be good reasons, in other contexts, for copying the causally-irrelevant actions performed by a majority, for example when the irrelevant actions embody social, normative, conventional, and/or ritualistic functions (e.g., Keupp et al., 2013, 2015; Legare et al., 2015; Nielsen & Blank, 2011; Over & Carpenter, 2012).

In the current study we investigated just how optimal children's imitation is. Specifically, we asked whether children can fine-tune majority-biased copying to include causally-irrelevant actions when these actions embody socially-relevant functions. In doing so, we clarify further what causes causally-irrelevant action copying, and further test social and normative accounts of "over-imitation" (e.g., Kenward et al., 2011; Keupp et al., 2013; Over & Carpenter, 2012). We tested 4- and 6-year-olds, as in Evans et al. (2018), and expanded the experimental framework adopted by Evans et al. by additionally incorporating social observers, who provided an evaluation of the actions displayed by the demonstrators.

As in Evans et al. (2018), children watched a video demonstration showing four people retrieving a reward from a novel puzzle box in turn. While doing so, the majority group (three demonstrators) each performed an irrelevant action, while a single minority demonstrator omitted it. Unlike Evans et al., and following Fusaro and Harris (2008), the video demonstration also showed three observers in the background who watched from a position screen-in-screen. In the 'approval/disapproval' condition, while the majority performed the irrelevant action, these observers nodded and smiled approvingly, whereas while the minority person omitted the irrelevant action, they shook their heads and frowned disapprovingly. The rationale behind this condition was that if a community of observers approved of the irrelevant action, this could convey that, even if it was causally unnecessary, there must be some other reason why it was important to perform (e.g., it had some social/conventional/normative/ritualistic function). Children's imitation of the irrelevant action in the approval/disapproval condition was compared to that in a 'neutral' condition, in which the observers watched all the demonstrations neutrally, expressing no approval or disapproval of either the majority's performance of the irrelevant action or the minority's omission of it.

We predicted that children are broadly optimal imitators who would incorporate these cues of social approval into their learning and exhibit flexible majority-biased copying. We thus predicted that the causally-irrelevant action performed by the majority would be copied more often in the approval/disapproval condition, where it had been awarded socially-functional properties by observers. We also predicted that older children would show higher rates of copying of the irrelevant action than younger children in the approval/disapproval condition. Prior work has shown that older children are more sensitive to the level of conventionality and the potential social pressures behind the activity (e.g., Herrmann et al., 2013; Keupp et al., 2015, Moraru et al., 2016), and that children's rates of faithful imitation increase with age as children become increasingly attuned to social norms (e.g., Clay et al., 2018; Legare et al., 2015).

2. Method

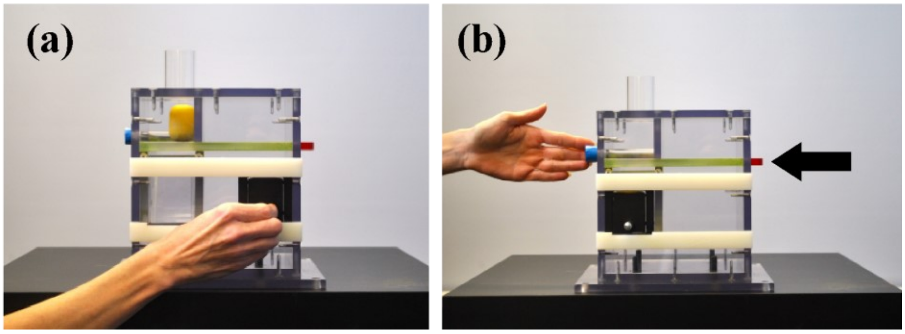
2.1 Participants

Eighty children aged 4 or 6 years were recruited from the St Andrews Aquarium, Scotland. There were 39 4-year-olds (*M*=53.4 months, range = 48-60 months, 18 females) and 41 6-year-olds (*M*=77.5 months, range = 71-83 months, 19 females). No SES data were collected. All children spoke fluent English. Parents provided informed consent and children verbally assented to participating.

2.2 Materials and Design

A two-action, transparent apparatus, the 'Sweep-Drawer Box' (Wood et al., 2013b, see Figure 1), was used for the imitation test. Retrieval of a capsule containing a sticker reward was dependent on the capsule being moved to a sliding black opaque exit door using one of two spatially-separated and functionally-independent task manipulandi: (1) a silver sweeper with a blue handle could push the capsule through a hole in the platform (Figure 1a), or (2) a blue drawer with a red handle could be pulled out, thereby creating a hole in the platform through which the capsule could fall (Figure 1b). For demonstrations that included an irrelevant action, the irrelevant action involved the demonstrator additionally sliding the door open and closed twice before using the sweeper retrieval manipulandum. A previous study showed that the retrieval manipulandum used during demonstrations (i.e., sweeper vs. drawer) did not influence children's tendency to copy the irrelevant action (Evans et al., 2018); therefore, in this study none of the demonstrations used the drawer manipulandum.

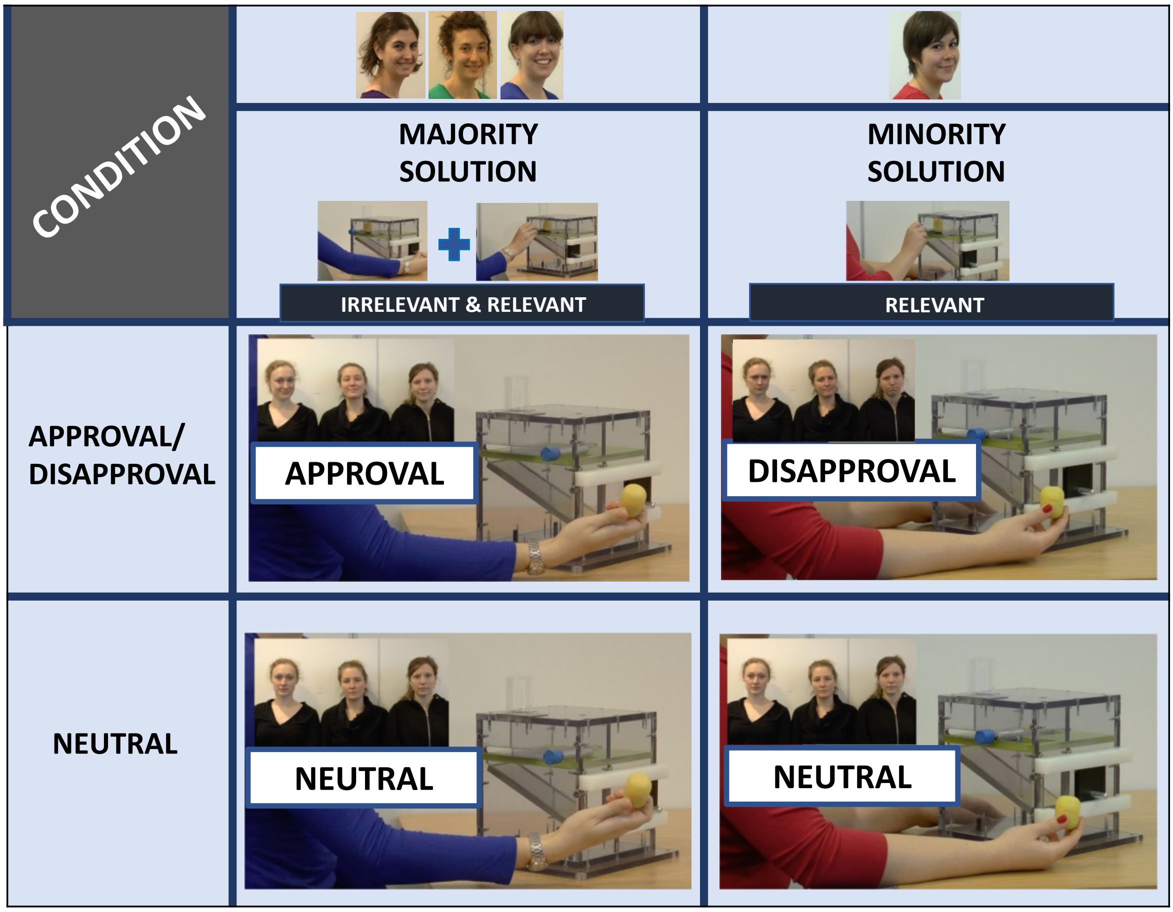
Figure 1. The Sweep-Drawer Box. The demonstrator (a) performs the irrelevant action on the door prior to capsule release, and (b) releases the capsule by pushing the sweep manipulandum (black arrow indicates the alternate, undemonstrated drawer manipulandum that could be pulled to release the capsule).



In a between-groups design, children were randomly assigned to either the approval/disapproval or the neutral condition, resulting in 20 children in each age group in the approval/disapproval condition and 19 4-year-olds and 21 6-year-olds in the neutral condition.

All children watched a video showing four female demonstrators, each wearing a different-colored shirt, retrieving the capsule from the apparatus in turn. In both conditions, children saw the majority (each of three demonstrators) perform the irrelevant action before using the causally-relevant sweep retrieval mechanism, and the minority (one demonstrator) use only the causally-relevant sweep retrieval mechanism, omitting the irrelevant action. To control for frequency effects, the minority demonstrator was shown retrieving the capsule three times in succession, while the majority demonstrators were shown retrieving the capsule once each. Following Fusaro and Harris (2008), video demonstrations in the approval/disapproval condition included footage of three female onlookers, appearing in a screen-in-screen position in the top left of the video (see Figure 2), nodding and smiling their approval throughout each demonstration performed by the majority and shaking their heads and frowning in disapproval throughout each demonstration performed by the minority. In the neutral condition, in contrast, the three onlookers displayed neutral expressions (without nodding or shaking their heads) throughout the demonstrations provided by both the majority and the minority. The identity of the minority demonstrator and the order in which the majority and minority demonstrators performed were counterbalanced.

Figure 2. Figure detailing the research design.



2.3 Procedure

Children were tested individually in a private area of the science center. Parents stood a few feet away and were asked to refrain from interacting with children if possible during the test. Children were first shown the apparatus and that stickers were inside the capsules (labelled “eggs”) that were put inside the box. The experimenter (E) told them, “This is my box. I’m going to put this [the capsule] inside the box. All you have to do is try to get it back out of the box. You can keep any stickers that you get out of the box.” Children were then shown a printed photograph of the four demonstrators and told, “Earlier I showed the box to four people and asked them to take a turn at getting the egg out. I made a video of what they did. You can watch the video of them taking a turn.” .

Children then sat at a table in front of an iPad display screen, with the apparatus still visible on the same table. All video demonstrations began with a still image of the four demonstrators, accompanied by the narration: “Earlier I showed the box to four people and asked them to take a turn at getting the egg out. Watch closely to see what they did.” The narrator also pointed to the observers, saying: “Look up here! Each time someone takes a turn, these people will watch how she does it.” The first demonstrator, who was sitting and smiling at the camera, was then introduced by the narrator, who said, “Here’s the person wearing the (e.g., blue) top. This is her taking a turn.” Then the camera panned out to show her sitting next to the apparatus, ready to take her turn.

Children then watched the film of each demonstrator taking a turn. Each demonstrator wore a different-colored shirt. The camera panned in to show only the demonstrator’s sleeves and hands (Wood et al., 2012) operating the apparatus. This was done in order to eliminate possible differences in ostensive cues between demonstrators, while still displaying the demonstrators’ different-colored shirts. Children watched three demonstrations by the minority model and one demonstration by each of the three demonstrators in the majority. In the approval/disapproval condition, children watched the onlookers approve the demonstrations by the majority (who used irrelevant actions) and disapprove the demonstrations by the minority (who did not use irrelevant actions). In the neutral condition, the onlookers watched all demonstrations with neutral expressions. After all four demonstrators had retrieved the capsule, the video footage returned to the initial still image of all four demonstrators.

E then removed the iPad and placed the apparatus directly in front of children and told them it was now their turn to get the sticker out of the box. Children were asked to choose a sticker, which E put into the capsule and inserted into the apparatus. Children were then free to approach and interact with the apparatus. There was no time limit given as all children released the capsule in just a few seconds. If children were hesitant or did not know what to do, children were further encouraged, "You can do anything you like to get the sticker out." On successful retrieval of the capsule, E removed the sticker and placed the sticker aside for children to keep. Children were offered two further trials (T2 and T3), in which case E reset the apparatus out of sight while children chose additional stickers. All children were offered stickers as a thank you gift for participating.

2.4 Coding and analysis

Children were scored for three measures on each response trial: (i) whether they were successful at removing the capsule, (ii) number of times they performed the irrelevant action, and (iii) whether they used the sweeper or drawer to retrieve the capsule. E and a coder blind to hypotheses coded children's performance from the video records. There was perfect agreement on all measures. All analyses were carried out in R version 3.4.0. Two-tailed *p* values are reported throughout.

3. Results

All eighty participants were successful at retrieving the capsule in each trial except for one 6-year-old who decided on his third trial that he was finished with the experiment. Preliminary analyses revealed no effect of participant sex or demonstration order (majority or minority first) on any of the dependent variables; thus these are not discussed further. Additional preliminary analyses showed that children were more likely to use the demonstrated sweeper manipulandum than the undemonstrated drawer to retrieve the capsule, and that discovery of the undemonstrated method of drawer retrieval did not differ by condition or age (See Supporting Information S1).

A logistic generalized linear mixed model (GLMM) was fitted to examine the effects of condition, trial, and age and their three-way interaction on whether children copied the majority's irrelevant action (see Supporting Information S2 for further details of the regression model and post-hoc contrasts). A main effect of condition demonstrated the predicted increase in copying of the majority's irrelevant action when observers approved it (66% of trials) relative to when observers were neutral (13% of trials; odds ratio =152.93, $p<.001$; see Table S3). The effect of observer approval on increased copying of the majority's irrelevant action was observed in both older and younger children (see Table S4). Moreover, a significant interaction between condition and age revealed that the increase was more pronounced in 6-year-olds (majority copying in 81% of trials in the approval/disapproval condition vs. 11% in the neutral condition) compared to 4-year-olds (majority copying in 50% of trials in the approval/disapproval condition vs. 16% in the neutral condition; odds ratio = 0.13, $p<.03$; see Table S5 and Figure 3), confirming our expectation that older children would show a greater tendency than younger children to integrate socially-relevant cues about causally-irrelevant actions into their response. There was also a main effect of trial (% of children copying the irrelevant action: T1=50%; T2=33%; T3=35%), with paired contrasts revealing a reduction in irrelevant action copying in T2 compared to T1 (odds ratio = 6.82, $p<.01$), and T3 compared with T1 (odds ratio = 4.76, $p<.05$), but not in a comparison between T2 and T3 (odds ratio = 0.7, $p=.81$ see Table S6 and Figure S1).

Figure 3. The percentage of children copying the majority at T1 and pooled across all responses (T1-T3) combined by age and condition. The dashed line represents copying at the level represented by the majority of demonstrators (75%, i.e., the percentage, 3 of the 4,

demonstrators who comprised the majority): asterisks indicate that majority copying differed significantly from the demonstrated level of 75% (****p*<.001). Brackets represent significant differences between conditions identified by a GLMM conducted on data pooled from all responses T1-T3 (see Supporting Information S2; † *p*<.05, ††† *p*<.001).

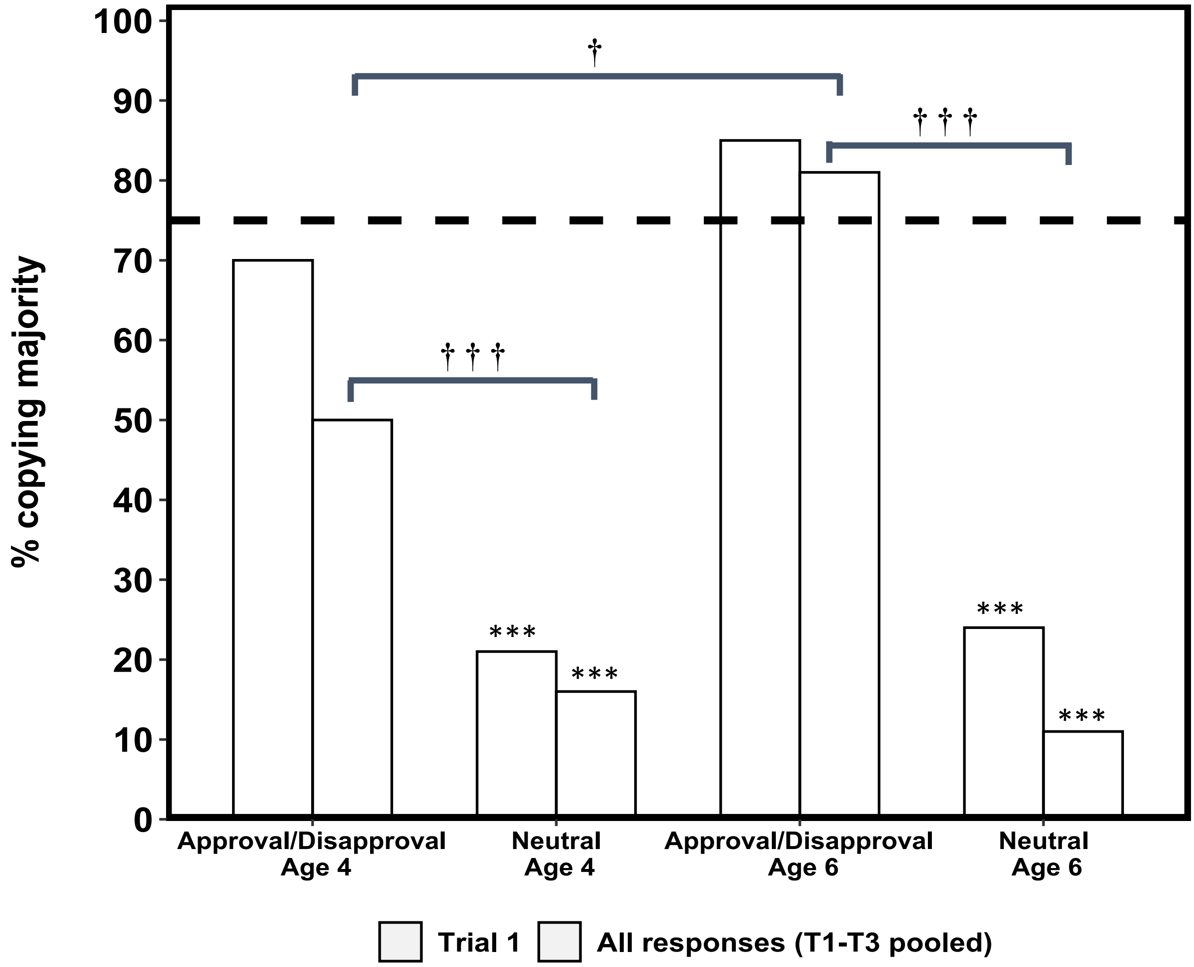


Figure 3 shows the breakdown of majority copying by condition and age, for both Trial 1 separately and pooled across all three trials combined. It confirms our expectation that children would exhibit majority-biased copying flexibly, showing an increased tendency to copy the majority's irrelevant action in the approval/disapproval condition where it had been awarded socially-relevant properties by others.

Since cultural evolutionary theory suggests that a behavior must be copied at levels proportional to its representation in the population if the trait is to be maintained at current levels (Boyd & Richerson, 1985), we compared children's responses to the majority-demonstrated level of 75%, i.e. the percentage of demonstrators who comprised the majority. In the approval/disapproval condition, 4-year-olds copied the irrelevant action at levels similar to the majority-demonstrated level of 75%, both in their first trial (T1: 70% copied majority; binomial test proportion = 0.75: ±95% [46%, 87%]; p=.797) and overall, across all three trials combined (T1-T3: 50%; option-bias test statistic [see Supplementary Information S3] = 18.69; p=.530), and this pattern was even more pronounced in 6-year-olds (T1: 85% copied majority; binomial test proportion = 0.75: ±95% [61%, 96%], p<.439) and overall, across all three trials combined (T1-T3: 81%; option-bias test statistic = 0.95; p<.96). In the neutral condition, in contrast, majority copying occurred at levels significantly below the demonstrated level of 75% (i.e., children at both ages were significantly more likely to use the minority's more efficient solution and omit the irrelevant action: for 4-year-olds, T1: 21% copied majority; binomial test proportion = 0.75: ±95% [7%, 46%], p<.001; T1-T3: 16%; option-bias test statistic = 103.44; p<.001; for 6-year-olds, T1: 24% copied majority; binomial test proportion = 0.75: ±95% [9%, 48%], p<.001; T1-T3: 11%; option-bias test statistic = 133.76; p<.001).

4. Discussion

These results contribute important new perspectives to our understanding of social learning biases and the copying of causally-irrelevant actions, bringing further into focus their fine-tuned integration in the cultural evolutionary process. Specifically, we show that both 4- and 6-year-old children copied both the majority and irrelevant actions highly flexibly, incorporating the irrelevant actions of the majority into their own task performance when these actions were socially approved, but selectively omitting them in favor of the minority's alternate efficient solution when there were no obvious social benefits. A previous study suggested that children might more accurately be cast as "optimal-" rather than "over-" imitators, after finding that they flexibly adjusted majority-biased copying heuristics, dropping majority-biased copying when the majority performed irrelevant actions, at least in purely instrumental contexts (Evans et al., 2018). Our results cement this earlier suggestion, and extend this previous work by additionally demonstrating that children also integrate information about social approval when fine-tuning majority-biased copying, over-riding the dropping of irrelevant actions when the actions were conveyed as normative. We thus contribute further evidence to the increasing doubts about whether children are best characterized as over-imitators (e.g., Evans et al., 2018; Hoehl et al., 2019; Keupp et al., 2013), by demonstrating that children's imitation is optimally calibrated across multiple learning cues.

Our results suggest that social learning biases work in ways that are broadly optimal for the cultural evolutionary process, even in early childhood. We have shown that children favor copying efficient actions over a majority and only adopt the majority behavior when it is socially optimal to do so. Rather than "over-imitating" blindly, this selectivity facilitates the delicate balance of the two engines of cultural learning – imitation vs. innovation (e.g., Legare & Nielsen, 2015) – allowing both the maintenance and the modification of learned behavioral traits.

It is likely that this selectivity and flexibility extends even further, to both the content and the context of the demonstration. With regard to content (e.g., the type of action to be imitated), we might expect the strategic and flexible copying of causally-irrelevant actions shown here to extend to actions that are causally-relevant. For example, there may be multiple efficient ways to perform a goal (e.g., eating with chopsticks vs. a fork), but the chosen action may depend on the culturally-accepted method. Future research could investigate whether the attention children pay to social approval extends to majority-biased copying of causally-relevant actions as well.

With regard to context (e.g., type of model, such as the make-up of the majority), here we show that children are unlikely to copy just any majority. Rather than using the blanket social learning strategy “copy the majority,” children optimally adopted the more fine-tuned strategy “copy the majority when the group approves of their behavior.” This finding thus adds to a small but growing body of work on children’s selective copying of the majority: Children know that one should copy the majority when it is successful or reliable (Bernard et al., 2015; Wilks et al., 2015), when it has the best information or is older (Einav, 2014; Kim & Spelke, 2020; McGuigan & Burgess, 2017), when it acts unanimously (Evans et al., 2018), and, as we have shown here, when it receives social approval. Future research could further investigate whether the composition of the majority/minority, as well as the observers, influences children’s copying. For example, Oostenbroek and Over (2015) have shown that 5-year-old children contrast their behavior to that of out-group members, so it is likely that if the majority and/or the approving observers were clear out-group members, children might behave differently.

Future work is also needed to understand the impact that social approval has on the longevity of learned behavioral traits. Cultural evolutionary theory suggests that a behavior must be copied at levels proportional to its representation in the population if the trait is to be maintained at current levels (Boyd & Richerson, 1985). Our results show that children demonstrated copying of the irrelevant action at levels proportional to its demonstrated frequency, which persisted across trials, after having witnessed observers who approved of these actions. This further supports the idea that socially-approved, majority-biased copying could stabilise irrelevant action copying over time. It is likely that social approval cues strengthen normative learning and reinforce the spread and maintenance of norms (Wen et al., 2020). Understanding these social cues and the norms they represent is important for understanding and even altering cultural practices. For example, recent studies have shown that by understanding the strength of perceived approval from close family and community and applying an understanding of cultural evolution processes, one can design and implement targeted interventions to reduce harmful cultural practices (Efferson et al., 2020). Since the importance of social approval likely varies across cultures (e.g., see work on cross-cultural differences in conformity by Corriveau & Harris, 2010, and Corriveau et al., 2017), it would be important for future research to include carefully-chosen cross-cultural comparisons to investigate how children in different cultures weight the relative importance of social approval and the actions of the majority.

The human capacity to fine-tune learning strategies may be one of the fundamental components of human cultural learning that set our species apart from others. Overall, our results demonstrate that children are broadly optimal imitators who integrate social, normative, and causal information to selectively copy behaviors according to the unique situation they are in. Children imitate majorities but only when it makes rational sense to do so. The human ability to be selective in the crucial balance between imitation and innovation is integral to understanding cumulative cultural evolution.

Data Availability

All data and the variable handbook that accompany this study are publicly available from the OSF at the following DOI: https://doi.org/10.17605/OSF.IO/QY842

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Supporting information for:

When does it pay to follow the crowd? Children optimize imitation of causally irrelevant actions performed by a majority

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Contents:

S1. Preliminary analyses of children's tendency to use the demonstrated sweeper manipulandum versus the undemonstrated drawer manipulandum

Children were significantly more likely to use the demonstrated sweeper manipulandum than the undemonstrated drawer manipulandum to retrieve the capsule in each trial (T1: 90% sweeper, $\chi^2(1)=51.2$, $p<.001$, $N=80$; T2: 86.3% sweeper, $\chi^2(1)=42.1$, $p<.001$, $N=80$; T3: 88.6% sweeper, $\chi^2(1)=47.1$, $p<.001$, $N=79$; 86.3% of children used the drawer at least once across all trials, $\chi^2(1)=42.1$, $p<.001$, $N=80$). Whether or not children discovered the drawer method of retrieval did not differ by condition (approval/disapproval: 15% used the drawer method, $N=40$; neutral: 12.5%, $N=40$; Fisher's Exact Test: $p=1$), or age (age 4: 17.9%, $N=39$; age 6: 10%, $N=41$; Fisher's Exact Test: $p=0.34$).

S2. Detailed description of the logistic regression models performed to test for effects of condition, age, and trial on whether children copied the irrelevant action

A Bayesian logistic generalized linear mixed model (GLMM), with standard errors adjusted for repeated measures on participants, and a three-way interaction term comprising the factor variables 'condition', 'trial', and 'age group', was fitted using the R package blmer (Dorie, 2015). Quasi-separation in the data required the use of weak normal priors on the fixed effects (Bolker, 2017). The results of a model with normal prior variance of 2.25 are reported; however, prior sensitivity was tested across a range of prior variances from 2.25 to 16, with no changes in variable selection outcomes (see below) or the direction of effects.

The dredge function in the MuMIn package (Barton, 2015) was used to undertake an exhaustive search of all predictor variable combinations, in order to identify the best possible model using AICc model comparison (Burnham & Anderson, 2002). Model selection was undertaken only for the fixed effects and marginality constraints on interaction effects were respected during model selection (i.e., candidate models containing interaction effects always retained the respective lower-order main effects represented in the interaction).

Significance testing of main effects and interactions was undertaken using likelihood-ratio (X^2) tests and AICc (a reduction in AICc of 2 or more was regarded as evidence that inclusion of an independent variable significantly improved model fit; Burnham & Anderson, 2002). Posteriori comparisons, with Tukey correction for familywise error rate, were performed on the estimated marginal means using the package *emmeans* (Lenth, Singmann, Love, Buerkner, & Herve, 2020).

Table S1: *Model selection table: top models ranked by AICc following exhaustive search of all possible predictor variable combinations*

Model Rank	(Int)	Condition	Age Group	Trial	Condition*AgeGroup	Condition*Trial	df	logLik	AICc	Delta AICc	Model weight
1	1.1	+	+	+	+		7	-83.071	180.6	0	0.651
2	1.201	+	+	+			6	-85.637	183.6	3.01	0.144
3	1.605	+		+			5	-86.934	184.1	3.5	0.113
4	1.002	+	+	+	+	+	9	-82.88	184.5	3.92	0.092

A random effect for repeated measures on participants was included in all models. All models differing from the top model by a Delta AICc < 4 are listed in Table S1 (a Delta AICc of 4 or more is regarded as indicating very little support for a model; Burnham & Anderson, 2002). The top model identified (Model Rank 1 in Table S1, detailed further in Table S2 below), contained a main effect of trial, and an interaction between condition and age (along with the respective lower-order main effects) was well-supported with a model weighting of >65%, and a Delta AICc >3 from the second-ranked model.

Table S2

The effects of predictor variables included in the final model on whether children copied the irrelevant action of the majority

Model parameters	Estimate (S.E.)	Odds ratio
Intercept	1.10 (0.75)	3.01
Condition[a]	-3.87 (1.00)***	
Age[b]	2.05 (0.94)	
Trial (T2) [c]	-1.92 (0.59)*** †	0.15
Trial (T3) [d]	-1.56 (0.58)*** †	0.21
Condition*Age	-2.32 (1.11)*	

Logistic GLMM with a random effect for repeated measures on participants. All interaction terms were retained with their respective main effects and lower-order terms during model selection. Significance testing of the fixed effects in the final (top) model was carried out using likelihood-ratio tests (X^2). (Odds ratio effect sizes are given only for model parameters not included in a second-order interaction; post-hoc paired contrasts and interaction effects are detailed separately in Tables S3 to S6.)
a Dichotomous variable (0 = approval/disapproval, 1 = neutral)
b Dichotomous variable (0 = age 4, 1 = age 6)
c Dichotomous variable (0 = Trial 1/Trial 3, 1 = Trial 2)
d Dichotomous variable (0 = Trial 1/Trial 2, 1 = Trial 3)
† All levels of the predictor variable Trial were assessed using a single likelihood ratio test and were examined further with Tukey post-hoc comparisons in Table S3 below.
*p<.05; **p<.01; ***p<.001 (obtained using likelihood-ratio tests (X^2))

Table S3

The effect of condition on whether children copied the irrelevant action of the majority

Model Parameter	Contrasts	Estimate (S.E.)	Odds ratio
Condition	Approval/Disapproval - Neutral	5.03 (0.97)***	152.93

Model relates to final model presented in Table S2. Contrasts obtained from the estimated marginal means.
****p*<.001

Table S4

The effect of condition on whether children copied the irrelevant action of the majority by age

Grouping factor: Age	Contrasts: Levels of Condition	Estimate (S.E.)	Odds ratio
4-year-olds	Approval/Disapproval – Neutral	3.87 (1.00)***	47.94
6-year-olds	Approval/Disapproval – Neutral	6.19 (1.23)***	487.85

Model relates to final model presented in Table S2. Contrasts obtained from the estimated marginal means.
****p*<.001

Table S5. *The interaction of condition and age on whether children copied the irrelevant action of the majority*

Condition: Factor level included	Contrasts: Levels of Age	Estimate (S.E.)	Odds ratio
Approval/Disapproval	Age 4 – Age 6	-2.05 (0.93)*	0.13
Neutral	Age 4 – Age 6	0.27 (1.11)	1.31

Model relates to final model presented in Table S2. Contrasts obtained from the estimated marginal means.
**p*=.03

Table S6

Tukey pairwise comparisons of the effect of trial on whether children copied the irrelevant action of the majority

Model Parameter	Pairwise comparisons	Estimate (S.E.)	Odds ratio
	Trial 1 – Trial 2	1.92 (0.59)**	6.82
Trial	Trial 1 – Trial 3	1.56 (0.58)*	4.76
	Trial 2 – Trial 3	-0.36 (0.59)	0.70

Model relates to final model presented in Table S2. Comparisons obtained from the estimated marginal means. Tukey correction for familywise error.
**p*<.05; ***p*<.01; ****p*<.001

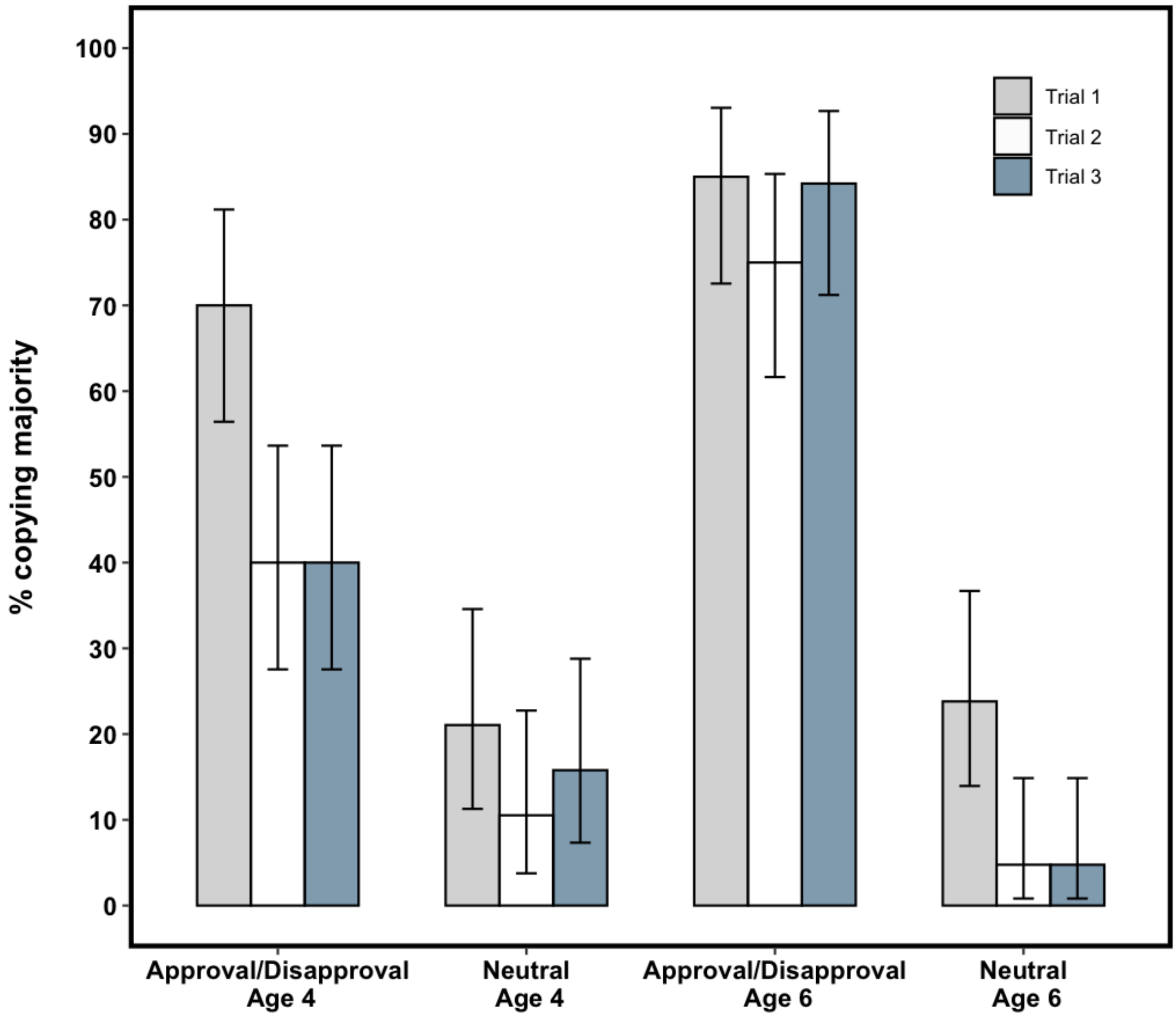

Figure S1. The percentage of participants who copied the majority's irrelevant action by condition, age, and trial (binomial standard errors calculated using the Pearson Klopper method)

S3. Description of the option-bias method and supporting R code

To assess whether children demonstrated an overall bias towards copying the irrelevant action of the majority across all response trials combined (i.e., data pooled across T1-T3), we adopted the option-bias method (Kendal et al., 2009), which employs a randomisation procedure (Manly, 2007) to account for within-individual correlations in responses (i.e., repeated measurements on participants) across trials.

This comprised performing a binomial test on the proportion of total trials in which the majority was copied against a test proportion of 0.75 (i.e., the frequency of demonstrators that demonstrated majority behaviour), and then comparing the resulting option bias test statistic ($\mathcal{X}^2$) to the expected null distribution when no preference for the majority or minority solution was observed. The null distribution was computed by randomizing the observed data, recalculating $\mathcal{X}^2$, then repeating this 10,000 times. The null hypothesis could be rejected when the probability (*p*) that the randomization procedure generated a $\mathcal{X}^2$ value at least as big as that calculated for the original data was <0.05.

```
xdata <- “load study datafile”
ouputDF <- c() # Prepare Output

for(cond in 1:2) {
# select data for one condition only (1=Approval; 2=Instrumental)
test.data=subset(xdata, condition==cond)
# select those individuals that respond at least once to majority or minority container
test.data=subset(test.data, apply(test.data[,c("N_Maj","N_Min")], 1, sum)>0)
inputData <- test.data[, c("N_Maj","N_Min" )]  # cut down test.data
inputData1 <- test.data[,c("N_Maj")] # num times majority option chosen
# calculate total num of (majority + minority) responses made by each individual
 inputData2<-test.data[,"N_Maj"] + test.data[,"N_Min"]
 NoRand<-10000 #Set number of randomizations
#Calc test statistic: the binomial test of proportions for copying at 75%
testStat<-sqrt((prop.test(sum(inputData1), sum(inputData2), p=0.75)$statistic)^2)
null<-rep(-999,NoRand) #initialize null distribution
#Randomise responses within individuals
 for(j in 1:NoRand){
 randData<-matrix(nrow=dim(inputData)[1], ncol=2) #initialize matrix for randomized data
 for (i in 1:dim(inputData)[1]){
 randData[i,]<-as.numeric(inputData[i,order(runif(2))]) #randomize data
}
randData1<-randData[,1]  # num times majority option chosen for randomized data
#Calculate test stat for randomized data and put in null
randData2<-randData[,1] + randData[,2] # calculate total num of (majority + minority)
responses made by each individual for randomized data
null[j]<-sqrt((prop.test(sum(randData1), sum(randData2), p=0.75)$statistic)^2)
distribution
    }
#Record output
ouputDF = rbind(ouputDF, data.frame(Condition=cond, majority=(sum(test.data[,
c("N_T_Maj")])/(sum(test.data[,c("N_Maj","N_Min" )])))*100,
minority=(sum(test.data[,c("N_Min" )])/(sum(test.data[,c("N_Maj","N_Min" )])))*100,
ts=testStat, P= (sum(null>=testStat)+1)/(length(null)+1)))
```

```
	}
ouputDF  #print results
```

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