Transmission Chain Methods

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(a) Tasks

Participants were randomly assigned to build one of two tools: (a) a floating container made from a single sheet of waterproof paper or (b) a carrying container made from 30 identical, 30cm long pipecleaners. The two tool types were chosen for their differences in causal opacity; while paper tools are relatively simple and easy to reverse-engineer, pipecleaners can be attached together in a wide variety of different ways and their "furriness" makes it difficult to see how the individual elements join and overlaps. Pilot studies confirmed the differences in opacity: naïve participants could readily reproduce paper tools but needed the original maker to teach them to accurately reproduce pipecleaner tools.

(b) Participants

624 participants took part in the main experiment. Of these, 600 participated in "transmission chain" groups of 10 individuals. Groups were pseudo-randomly allocated to tasks (building a tool out of either paper or pipecleaners) within one of three social learning conditions (emulation; imitation or teaching), giving 10 replicate groups of each task and social learning condition. The remaining 24 participants were allocated to the Asocial learning condition, in which they made 10 consecutive paper tools (N=12 participants) or pipecleaner tools (N=12) with no opportunity to learn from others. We recruited participants from local community groups (N = 38 groups and 15 Asocial; age 16-89) and the student body at the University of Exeter and Truro College (N = 22 groups and 9 Asocial; age 16-56) and incentivised participation with a £1000 reward for the groups that produced the highest-performing paper and pipecleaner tools.

(c) Procedure

We ran experiments in classrooms, laboratories and community group rooms, with screens to separate areas for building and testing tools. Before starting the experiment, each participant read an information sheet and completed a consent form. We randomly allocated participants from social learning conditions to a position from one to ten within their transmission chain.

Each participant in turn was then called into the experimental room. Here, they sat at a desk and were given written and verbal instructions to build, within five minutes, a tool from the materials provided (one sheet of waterproof paper or 30 identical, 30cm long pipecleaners) to carry as many marbles as possible. The instructions specified that (a) paper tools must float on water before receiving marbles and (b) pipecleaner tools must be held by one or more handles incorporated in the design. Participants in the Asocial treatment instructed to build a total of ten tools. A stopwatch clearly displayed the time elapsed and we updated builders periodically on their remaining time.

After the allocated building time elapsed, participants moved into a screened-off testing area, which contained a bowl filled with marbles of two different sizes (totalling 3kg) and a scoop. Builders of paper tools were asked to float the tool in a tray filled with water and load as many marbles as possible into it without it sinking. In the pipecleaner condition, builders were asked to load as many marbles as possible into the tool before carrying it to a set of weighing scales 5m away. There was no time restriction for testing. We then recorded the number of marbles of each size and whether or not the paper tools took on water. After testing participants were then either guided to a waiting area or, for participants in teaching treatments, asked to stay behind to help other group members. At the end of the procedure participants filled in a debrief form that included a likert scale question regarding their experience with handiwork or craft-making on a scale of 0 to 4.

(d) Experimental conditions

We gave each participant written and spoken instructions relevant to their experimental condition. In the *Asocial* condition, participants were asked to build and test ten tools in succession, with no opportunity to observe or communicate with others. The participant's previous two tools were left on display after each round of building.

To address an important confound of most previous studies [1], we ensured that participants had access to social information for a standardised amount of time across conditions. In the *Emulation* condition, participants could not observe or communicate with other team members, but could examine up to two tools made by previous chain members. Start times were staggered so that each new participant (except the first two in each chain) could examine the tools two minutes before starting building as well as during the five minutes building time, giving a total of seven minutes of access to social information (Figure x; see supplementary material for further details).

In the *Imitation* condition, participants were allowed to observe earlier chain members building their tools, but could not communicate or touch the materials. Start times were staggered so that (from the third participant in the chain onwards) each new participant started observing two minutes after the participant two steps ahead started building. This allowed observation of the final three minutes building of this design and part observation of the participant one step ahead. Building commenced once the participant two steps ahead finished testing their tool and the focal participant was informed of their score (See Figure X). While building, participants were also free to continue to observe the participant one step ahead in the chain (and were informed of that participant's score as it was recorded), providing a total of seven minutes available for observation.

Finally, in the *Teaching* condition participants returned to the building area after testing their tool in order to help the next members of their group for ten minutes. During this "teaching role" they could communicate with group members, but could not physically assist in building or touch the materials. Start times were staggered so that (from the third participant in the chain onwards), each participant had one teacher (the person two steps before them in the chain) present for the full five minutes of building, with an additional teacher (the chain member three steps ahead) present for part of the time (receiving a total of 7 mins of teaching time; see Figure 1).

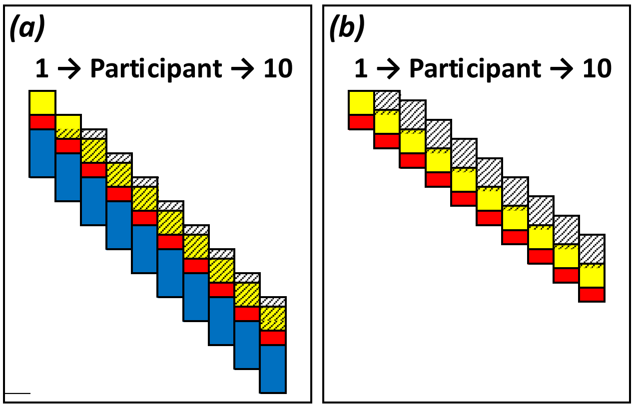

Figure 1. Design of transmission chains. Participants (1-10 within each chain) had five minutes to build their tools (yellow) and, from participant 3 onwards, access to social information for a standardised seven minutes (hatched areas). In (a) *Teaching* and *Emulation* chains, participants had access to social information for two minutes before starting building and throughout the building period. The 10 minutes during which participants acted as teachers or their tool was left in display are shown in blue. In (b) *Imitation* chains, participants could observe their predecessors for up to six minutes before building and an additional minute while building. Testing time (red) was unlimited, but for simplicity we depict it here as lasting three minutes (the mean time across all participants). Thus the actual chains were more fluid than these representations, within the parameters that learning (*Teaching* and *Emulation* conditions) and building (*Imitation* condition) always began when the participant two steps ahead in the chain finished testing their tool.

(e) Similarity measures

We used online surveys, built and administered using Qualtrix, to determine the similarity between different tools within transmission chains. Raters (blind to hypotheses and experimental conditions) were given detailed instructions and a tests of comprehension, which they had to pass in order to proceed with the survey.

Each survey question displayed two tools. Survey instructions explained that participants would be asked to rate how similar the two tools were in terms of (a) **Shape and features** (whether the two tools look alike in terms of their overall shape and design features) and (b) **Underlying Construction.** For paper tool surveys, underlying construction refers to whether the implement has been made using the same types of folds, with the same precision. In the pipecleaner tool surveys, underlying construction refers to whether the pipecleaners are attached together in the same same way, with similar-sized spaces between them.

Participants could either type their rating or click the cursor into an image of four stars and drag to highlight a score, ranging from 0.00 (no similarity) to 4.00 (identical). An example is shown below:

Before moving on in the survey, they had to demonstrate understanding of the rating method. They then went through a series of three quality control questions. In each question, they had to rate the similarity of two tools, which had been deliberately chosen to illustrate pairs of tools at the upper, lower and middle range of degrees of similarity. At the end of each question, participants were presented with a recommended similarity rating, which had been determined by the experimenter for that pair of tools. For instance: “In terms of Shape and Features the bottom implement looks to be an almost exact copy of the top. They are both rectangular boxes with deep sides, of identical proportions. We would suggest a score of 4. In terms of Underlying Construction the two implements have been constructed using exactly the same types of folds and with the same precision. We would suggest a score of 4.” Participants whose answers deviated from the recommended scores by more than 0.5, or who went through the instructions and quality checks too quickly were excluded from the final dataset.

We conducted two separate surveys for each tool type. Survey 1 quantified the similarity of every tool to its successor(s) within the same transmission chain. For each tool type, a total of 151 raters each rated the similarity of 20 different pairs of tools, such that each pair was rated by at least three different raters. We then used the mean rating as the measure of similarity for analyses. Survey 2 followed the same format, but compared randomly selected pairs of tools from the same generation (either generation 1, 5 or 10) across different transmission chains to provide measures of divergence or convergence in tool designs. Every pair of tools was scored by ten different raters, and we used the mean value as the measure of similarity.

(f) Statistical analyses

We analysed data in R 3.6.3 [2], using the package lme4 for linear (mixed) models. We assessed model fit using standard residual plot techniques. Response variables were transformed when necessary, and we checked for potentially highly influential datapoints by calculating Cook’s distances. We adopted an information theoretic approach to model selection, ranking models by AICc. The top model set contained models within AIC ≤6 of the of the lowest AICc value, and we applied the “nesting rule” [3] to avoid favouring overly complex models.

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