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## **The Pedagogue, The Engineer, Or The Friend: From Whom Do We Learn?**

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### **Running Head:**

From Whom Do We Learn?

## Abstract

Humans can follow different social learning strategies, sometimes oriented toward the models' characteristics (i.e., who-strategies). The goal of the present study was to explore which who-strategy is preferentially followed in the technological context based on the models' psychological characteristics. We identified three potential who-strategies: Copy the pedagogue (a model with high theory-of-mind skills), copy the engineer (a model with high technical-reasoning skills), and copy the friend (a model with high level of prosocialness). We developed a closed-group micro-society paradigm, in which participants had to build the highest possible towers. Participants began with an individual building phase. Then, they were gathered to discuss the best solutions to increase tower height. After this discussion phase, they had to make a new building attempt, followed by another discussion phase, and so forth for a total of six building phases and five discussion rounds. This methodology allowed us to create an attraction score for each participant (the more an individual was copied in a group, the greater the attraction score). We also assessed participants' theory-of-mind skills, technical-reasoning skills, and prosocialness to predict participants' attraction scores based on these measures. Results show that we learn from engineers (high technical-reasoning skills), because they are the most successful. Their attraction power is not immediate but, after they have been identified as attractors, their technique is copied irrespective of their pedagogy (theory-of-mind skills) or friendliness (prosocialness). These findings open avenues for the study of the cognitive bases of human technological culture.

**Keywords:** Technological Culture; Social Transmission; Technical Reasoning; Theory of Mind; Prosocialness.

## Introduction

Imagine that you live in a prehistoric time. To discover how to make fire, you have two options. The first is to orient attention to the physical world. For instance, you may be very lucky, seeing lightning striking a tree. This may give you enough time to find out a fire-making technique by yourself, through trial and error. This is an instance of asocial learning, because you learn from observing how the world works. For the second option, one does not need to be so lucky. Many members of your group may already have mastered fire-making techniques, increasing your probability of observing the phenomenon or being taught how to reproduce it. This is an instance of social learning because you benefit from copying others, taking a shortcut to acquiring information and saving yourself from the cost of asocial learning (for discussion about adaptive trade-offs between social and asocial learning, see Kendal et al. 2009). If you choose the second option, you have a major problem to be solved. There are many potential models in your group, so from whom will you learn?

The who-strategies – in Laland’s terms (Laland 2004; see also Hoppitt and Laland 2013; Kendal et al. 2018) – are an interesting aspect of social learning phenomena. These strategies characterize the model (e.g., copy successful individuals). The corollary is that the models’ characteristics could influence *indirectly* whether, from whom, and how well a learner acquires information socially. For instance, a learner can decide to copy some models because it is easy to learn from them. In this instance, this decision results indirectly from the fact that these models possess a high level of theory of mind, allowing them to transmit information efficiently. The goal of the present study is to explore this aspect, by examining which one out of the three selected who-strategies is preferentially followed in the technological context. Before presenting the experimental paradigm designed to tackle this question, we begin by introducing the three

psychological characteristics of models studied here, which can influence social learning in the human species.

As illustrated just above, the who-strategies followed by a learner might be influenced by the easiness with which the latter can learn from a model, raising the question of the psychological characteristics of those models who transmit information efficiently. Recently, Dunstone and Caldwell (2018) stressed that models facilitate the learning of others much more when they have an understanding of others' states of knowledge (i.e., theory of mind; see the "optimization of sender behavior, due to understanding of others' knowledge states" section in Dunstone and Caldwell 2018). In this case, models can be viewed as pedagogues, offering appropriate feedback or orienting the learners' attention toward relevant information in order to help them to reproduce, for instance, a given artifact (Osiurak et al. 2020). This perspective is consistent with evidence from the developmental literature that has indicated that teaching strategies could develop during childhood in parallel with theory-of-mind skills (see Strauss et al. 2002). This is also consistent with some theoretical accounts that have drawn an evolutionary link between pedagogy and technology. For instance, it has been suggested that the progressive complexity of technology could have favored the emergence of pedagogical skills critical to transmit more and more opaque building processes (Gergely and Csibra 2006, 2009). Therefore, a first who-strategy might consist in copying people with high theory-of-mind skills (i.e., pedagogues) because of their easiness of transmitting knowledge (i.e., "copy the pedagogue"). As explained above, the term pedagogue does not characterize only the individuals with high theory-of-mind skills. Nevertheless, we will use it hereafter to characterize those individuals.

A second strategy might consist in copying the most successful individuals (e.g., an individual with high tool-making competence), an adaptive strategy that increases the chances

for a learner to be successful. A significant body of evidence has indicated that young children or nonhuman species (e.g., chimpanzees, capuchin monkeys) can follow this strategy, sometimes in a relatively flexible way (Chudek et al. 2012; Kendal et al. 2015; Ottoni et al. 2005; Wood et al. 2015; for reviews, see Price et al. 2017; Wood et al. 2013). This raises the question of the psychological characteristics of these successful individuals in the human technological context. A potential answer to this question comes from a series of recent studies using micro-society paradigms wherein participants have, for instance, to build a paper airplane for flying as far as possible. Those studies have reported cumulative improvement in purely end-state emulative conditions (i.e., reverse engineering; Caldwell and Millen 2009; Derex et al. 2019; Zwirner and Thornton 2015; see also Caldwell et al. 2012, 2018). These findings have led us to consider the importance of physical causal reasoning (Osiurak and Reynaud in press; Osiurak et al. in press; Zwirner and Thornton 2015; see also Pinker 2010; Vaesen 2012) – hereafter called technical reasoning, namely, the ability to reason about physical object properties (Osiurak 2014). Technical reasoning might be useful for extracting relevant information from either the end-product itself or the model’s behavior. This may be particularly true when the building process is transparent (i.e., the end-product provides enough information about how it is built when looking at it) but not opaque. In this latter case, pedagogical skills could remain fundamental, as explained above (Morgan et al. 2015; Stout and Hecht 2017; Wasielewski 2014). Consistent with this, three recent studies have also shown that technical-reasoning skills (particularly the learners’) are a better predictor of cumulative performance than theory-of-mind skills when a transparent artifact had to be built (De Oliveira et al. 2019; Osiurak et al. 2016, 2020). In addition, evidence from neuropsychology and neuroimaging has demonstrated that technical reasoning is critical to making and using tools and could also be at work when people observe others performing a tool-use action (Goldenberg and Spatt 2009; Orban and Caruana 2014;

Osiurak and Badets 2016; Osiurak and Heinke 2018; Osiurak et al. 2010; Reynaud et al. 2016, 2019). To sum up, technical-reasoning skills are central when people intend to make artifacts. The corollary is that people with good technical-reasoning skills are more likely to be successful in any building task. This leads us to make an alternative – but not necessarily competitive – prediction to the “copy the pedagogue” strategy hypothesis, according to which engineers should be preferential attractors for other members of the group (i.e., “copy the engineer”, a translation of the copy the most successful individuals strategy in the technological context). Note that the term engineer will be hereafter employed to refer to individuals with high technical-reasoning skills and not to engineers strictly speaking.

A third potential who-strategy might consist in copying the models who exhibit altruistic/prosocial behavior characterized by a motive to cooperate with others, by helping, assisting, comforting or taking care of them (Caprara et al. 2005; i.e., copy friends in Laland’s terms). Evidence from the developmental literature is consistent with this, indicating that children are more likely to learn from children they like than those they like less (Flynn and Whiten 2012). This corroborates other findings obtained in children, which have stressed that social learning strategies are also guided by the motivation to belong to a group (Over and Carpenter 2013; Watson-Jones et al. 2016; but see Wilks et al. 2019). It has also been suggested that collaboration might be a critical factor for the development of technological culture in humans, by favoring the sharing of information (Dean et al. 2012; Moll and Tomasello 2007; Stout and Hecht 2017; Whiten and Erald 2012). The lack of collaborative engagement from some individuals can be highly detrimental for a group. For instance, some individuals can prefer to follow their own “ineffective” ideas instead of taking into consideration the effective artifacts built within the group. This may become a problem for the other members if the shared goal is to design effective artifacts at the group level. Thus, such antisocial behavior may progressively

lead the other members to ignore the productions made by those individuals and to pay much more attention to the productions proposed by the individuals showing clear signs of collaboration. The derived prediction is that prosocial people (i.e., friends) should be preferential attractors (i.e., “copy the friend”). Even if the notions of pedagogues and friends used here may appear similar, they are not. We mean by pedagogues those individuals who can transmit information efficiently (i.e., high level of theory of mind). However, this does not presuppose that they have a motive to do so. Inversely, friends engage more spontaneously in collaboration (i.e., high level of prosocialness). Nevertheless, this does not presuppose that they can transmit information efficiently.

Here we sought to tackle the who-strategy issue in an original micro-society paradigm, allowing us to test the “copy the pedagogue”, “copy the engineer”, and “copy the friend” hypotheses. Many micro-society paradigms employed in previous studies have focused on the content of the information being transmitted (Caldwell and Millen 2008, 2009; Morgan et al. 2015; Osiurak et al. 2016; Wasielewski 2014; Zwirner and Thornton 2015). These studies have provided important insights into the quality of social transmission in different social learning conditions (e.g., observation, teaching). Nevertheless, they have the inconvenience – for the present purpose – that the number of potential models is limited (1 or 2) and not chosen by the learner, but rather imposed by the experimenter. So, as in other works (Derex et al. 2013; Efferson et al. 2008; Mesoudi 2008; Mesoudi and O’Brien 2008; Morgan et al. 2012; Muthukrishna et al. 2014), we opted for a micro-society paradigm in which the number of models is larger (i.e., 6) and not imposed by the experimenter.

In this line, we developed a closed-group paradigm (Mesoudi and Whiten 2008), inspired from the “12-angry-men” movie, in which a jury made up of 12 men has to deliberate the



acquittal or conviction of a defendant through a series of votes by secret ballot and discussion rounds (**Figure 1**). There were 20 experimental groups, each consisted of six participants, who were asked to build the highest possible tower with wires. As illustrated in **Figure 1**, there were six individual building phases (corresponding to the votes by secret ballot in the 12-angry-men movie) and five discussion rounds (corresponding to the discussion rounds in the 12-angry-men movie). More specifically, participants began with an individual building phase, where they built a tower without communicating or observing the other members of the group (Building phase: Tower n°1). Then they were gathered to discuss the best solutions to increase tower height. After this discussion phase, they had to make a new building attempt, again individually (Building phase: Tower n°2), followed by another discussion phase, and so forth for a total of six building phases and five discussion rounds. We measured not only tower height but also, and more importantly, specific features allowing us to describe the tower structure simply and to compute an attraction score based on the capacity of a participant at phase  $p$  to influence the towers built by other participants at phase  $p+1$ . In addition, we assessed participants' theory-of-mind skills, technical-reasoning skills, and prosocialness in order to predict participants' attraction score based on these measures. We also explored whether different cultural lineages arose in experimental groups (i.e., the progressive building of a tower very similar between the members of the group compared to the towers built by the other groups). Indeed, the observation of different cultural lineages was of primary importance to demonstrate the presence of social learning in experimental groups (see Reindl and Tennie 2018). Finally, to examine whether cumulative culture occurred in our 20 experimental groups, we also added six control groups, which were not incited to talk about building techniques during discussion rounds, but to play a competitive game.

< INSERT FIGURE 1 ABOUT HERE >

## Method

### Participants

One hundred and fifty-six undergraduate students in psychology and cognitive sciences at the University of Lyon ( $M_{\text{age}} = 22.1$ ,  $SD_{\text{age}} = 3.6$ ; 111 females) took part in the experiment. All participants had normal or corrected-to-normal visual acuity. No participant had prior expertise in engineering (i.e., formal education or degree). We did not find any published study using the same closed-group micro-society paradigm as ours. So, our sample size was determined from studies using transmission chain paradigms, which included at least 10 chains of six participants to explore specific social learning conditions (Zwirner and Thornton 2015). Here, we doubled the number of participants (i.e., 20 groups of six participants in the experimental condition). Participants in the groups did not know each other. Informed consent was obtained from all the participants. The Ethics Committee of Department of Psychology of Lyon approved the study and the procedure was carried out in accordance with the relevant guidelines and regulation.

### Main experiment

The study first began with the main experiment (i.e., closed-group micro-society paradigm) followed by an individual testing session (see below). The task of the main experiment was to build the highest possible tower with 15 metal wires (20 cm long). One hundred and twenty participants were assigned to the experimental condition (20 groups of six participants) and the remaining 36 participants to the control condition (6 groups of six participants). Participants of the experimental groups started with an individual building phase (4 min long), in which they built a tower without communicating or observing the other members of the group (Building phase: Tower n°1). To do so, they were placed in six individual rooms, preventing them from

seeing the other members of their group as well as their towers. Then, they were gathered in one room to discuss the best solutions to increase tower height (4 min long). There was no restriction on what they could discuss (e.g., they could disclose the heights of their own towers). Simply, experimenters instructed participants that the goal was to exchange information in order to allow the members of the group to build the highest possible towers. Neither the towers built, nor any building material was given or on display in order to incite participants to communicate verbally. Indeed, evidence indicates that theory-of-mind skills could play a critical role in cumulative technological culture under pure verbal communication micro-society conditions (Osiurak et al. 2020). So, in order to not mask the potential role of theory-of-mind skills in the transmission process, we chose to let participants use only verbal communication. After this discussion phase, they had to make a new building attempt, again individually in six individual rooms (Building phase: Tower n°2), followed by another discussion phase, and so forth for a total of six building phases and five discussion rounds. The procedure was the same for the control groups, except that they were forbidden to discuss about tower building during discussion rounds. Instead, they played a competitive game (i.e., Time's Up!). Discussions were not recorded.

Three measures were collected from the main experiment. The first was the height of towers in cm. Each tower was positioned vertically and the measure was taken only after 10s. Therefore, the measure was sometimes taken on towers that had fallen down. The height corresponded to the distance between the table and the highest vertical point of the tower, but not to the total length of the tower. The second (Mean similarity) and third measures (Attraction) were based on the shape of towers, leading us first to characterize each tower on the basis of specific features. There were four features, which were determined from previous data obtained on the same task (De Oliveira et al. 2019; Osiurak et al. 2020): Convergence of feet: Yes *versus* no; Presence of a base: Yes *versus* no; Presence of intermediary columns: Yes *versus* no;

Presence of an antenna: Yes *versus* no. Each tower was photographed and characterized following these features by two experts (mean Cohen's Kappa of .95; see **Figure 2**). The mean similarity score corresponded to the mean number of features that a tower shared with the other towers of its group (i.e., 5 towers; within-chain similarity) and with all the towers of the 19 remaining experimental groups (i.e., 114 towers) or five remaining control groups (i.e., 30 towers; between-chain similarity; for a similar procedure, see Reindl and Tennie 2018). There were four features characterizing the towers, so the maximum mean similarity score was 4. For attraction, we identified the sum of divergent features between the tower built by one participant  $X$  at phase  $p$  and the towers built by the other five participants of the group at phase  $p+1$  ( $d_x$ ). Given that they were four features and five towers, the maximum score of divergences was 20. In some groups, the total score of divergence for the six participants was high (e.g., 67) and in others low (e.g., 47), suggesting variability in the propensity of each participant of each group to change the tower built from phase  $p$  to phase  $p+1$ . To take this variability into consideration, we divided the number of divergences between one participant and the other five participants (i.e.,  $d_x$ ) by the total number of divergences found for each participant (including the participant  $X$  and the other five participants (i.e.,  $\sum_{i=1}^6 d_{x_i}$ )). This led us to obtain the proportion of divergences for one participant relatively to the total number of divergences within the group. Finally, this proportion was subtracted from 1 to collect the attraction score for each participant. Here is the formula used to calculate the attraction score for a participant  $X$  from phase  $p$  to phase  $p+1$ , namely,  $A(X)_{p \rightarrow p+1}$ :

$$A(X)_{p \rightarrow p+1} = 1 - \frac{d_x}{\sum_{i=1}^6 d_{x_i}}$$

with  $d_x$  being the number of divergent features between the tower built by one participant  $x$  at phase  $p$  and the towers built by the other five participants at phase  $p+1$ .

< INSERT FIGURE 2 ABOUT HERE >

### **Individual testing session**

The individual testing session consisted of six tests used to assess theory-of-mind skills, technical-reasoning skills, and prosocialness. For theory-of-mind skills and technical-reasoning skills, we followed the same methodology as Osiurak et al. (2016). Theory-of-mind skills were measured with two tests known to assess these skills. The first is the “Reading-the-Mind-in-the-Eyes” (RME) test (Prevost et al. 2014), which consists of choosing which of four words best describes what the person in the photograph is feeling or thinking (36 items; Time limit: 3 min). The second, the comic strip (CS) task (Sarfati et al. 1997), corresponds to short three-pictures comic strips, showing a character performing a very simple action. The task is to choose which one of three answer cards is the most logical to complete the comic strip sequence (28 items, Time limit: 2 min). For technical-reasoning skills, participants had to complete two sub-tests of the NV7 battery (Bernaud et al. 1994), one requiring physical reasoning (NV7a; e.g., selecting among four pictures depicting four different nails the easiest one to hammer; 24 items; Time limit: 5 min) and the other involving visuo-spatial constructive skills (NV7b; e.g., selecting among four 3D geometrical shapes the one corresponding to a given 2D pattern; 38 items; Time limit: 5 min). For these four tests, we recorded the number of correct responses given within the time limit. Prosocialness was assessed with two scales that characterize prosocial behavior in everyday life, namely, a French version of the Prosocialness Scale for Adults (PRO; Barsics et al. submitted; Caprara et al. 2005) and a composite score based on three NEO-PI-R sub-scales of agreeableness focusing on prosocialness and altruism (Altruism, Compliance, and Tender-Mindedness; NEO; Costa and McCrae 1992). We conducted a factorial analysis with varimax rotation on the scores collected on the six tests ( $n = 156$ ). We obtained a three-factor solution

accounting for 69% of total variance (Factor 1: 28%; Factor 2: 22%; Factor 3: 19%). Factor 1 loaded mainly on NV7a (.86) and NV7b (.82), Factor 2 on RME (.87) and CS (.61), and Factor 3 on PRO (.68) and NEO (.81), corroborating previous results found on 390 participants (Osiurak et al. 2016). In total, these analyses confirmed that RME/CS, NV7a/NV7b, and PRO/NEO were orthogonal measures of theory-of-mind skills, technical-reasoning skills, and prosocialness, respectively. For the main experiment, we used the factor scores obtained from the corresponding factorial analysis as indicators of participants' theory-of-mind skills, technical-reasoning skills, and prosocialness.

### **Linear mixed model analyses (LMM)**

To investigate whether there was a significant improvement in tower height along the chains, we used a Linear Mixed Model (LMM) with Tower height as dependent variable, Group (Experimental vs. Control), Attempts (Tower n°1 vs. ... Tower n°6) and Group\*Attempts as fixed factors, and Subject (i.e., participant's identity), Chain number (i.e., chain's identity) and Age (i.e., participant's age) as random effects. In all the analyses reported here, Tower height corresponded to the height of the tower produced individually by each participant and not the mean height of the tower produced by the group. Age and Chain number were included as random effects in all the analyses reported here in order to control for the variability that existed between the different groups in terms of age distribution (i.e., some groups were older or had a greater age difference than others) or level of performance (i.e., some groups performed better than others). To examine the emergence of cultural lineages in our experimental groups, we used an LMM with Mean similarity as dependent variable, Comparison (Within-chain/Between-chain), Attempts (Tower n°1 vs. ... Tower n°6) and Comparison\*Attempts as fixed factors, and Subject, Chain number and Age as random effects. The fixed factor "Comparison\*Attempts"

was critical here because we could expect that the difference in terms of mean similarity between “within-chain” and “between-chain” would increase over the experiment (i.e., after several attempts). The influence of theory-of-mind skills, technical-reasoning skills and prosocialness on attraction score and tower height was tested using an LMM with Chain number and Age as random effects. Akaike’s Information Criterion value, corrected for small sample size ( $AIC_c$ ) was calculated for the LMM. Models were ranked in relation to each other using  $\Delta AIC_c$  values ( $\Delta i = AIC_c_i - AIC_{c_{min}}$ ). Akaike weights were computed ( $\omega_i$ ) to assess the likelihood of the model relative to the other models considered. All models were averaged to calculate predictor estimates and standard errors using full-model averaging method (Burnham et al. 2011). The LMM analyses and the full-model averaging method were respectively conducted using the lme4 and MuMIn packages in R 3.1.3.

## Results

**Figure 3** depicts the evolution of tower height in both the experimental and control groups over the experiment. An LMM was used with Tower height as dependent variable, Group (Experimental vs. Control), Attempts (Tower n°1 vs. ... Tower n°6), and Group\*Attempts as fixed factors, and Subject, Chain number and Age as random effects. This analysis revealed that only the model Attempts differed significantly from the null model ( $\chi^2(1) = 86.77, p < .001$ ). These results indicated that the opportunity of sharing information in the experimental group did not provide any significant benefit when compared to the control group.

< INSERT FIGURE 3 ABOUT HERE >

The main goal was to focus on the predictors of the attraction score. However, a first important question was to investigate whether we found the emergence of different cultural lineages in our experimental groups. So, we examined whether the chains differed from each

other in tower shape, with the presence of a greater within-chain similarity than between-chain similarity (**Figure 4a**). An LMM was used to test this aspect with Mean similarity as dependent variable, Comparison (Within-chain/Between-chain), Attempts (Tower n°1 vs. ... Tower n°6) and Comparison\*Attempts as fixed factors, and Subject, Chain number and Age as random effects. This analysis revealed that both the model Attempts and Comparison\*Attempts differed significantly from the null model ( $\chi^2(1) = 80.62, p < .001$ ;  $\chi^2(1) = 261.02, p < .001$ , respectively), suggesting that cultural lineages clearly emerged in experimental groups over the experiment. This contrasts with the clear absence of differences between within-chain similarity and between-chain similarity over the experiment in control groups (**Figure 4b**).

< INSERT FIGURE 4 ABOUT HERE >

The next two analyses concerned the influence of participants' theory-of-mind skills, technical-reasoning skills and prosocialness on the attraction score and tower height. Before conducting these analyses, an interesting question was to examine whether participants could be easily classified into "pedagogue" only, "engineer" only or "friend" only based on their scores of theory of mind, technical reasoning and prosocialness, respectively. Indeed, an alternative possibility was that most of the participants could possess two or three of these characteristics (e.g., a participant who was both engineer and friend). This possibility is however unlikely, because the proportion of such participants (i.e., 9/120) was very low: Only six out of the 120 participants had a factor loading  $> 0.8$  (see Methods for details about factor loadings) for both theory of mind and technical reasoning, two for both prosocialness and theory of mind, and one for both technical reasoning and prosocialness. No participant possessed the three characteristics. In broad terms, our participants could be largely classified as being pedagogue, engineer, or friend.



We then focused on experimental groups by computing an attraction score (i.e.,  $A(X)_{p \rightarrow p+1}$ ) for each participant  $X$  and for each building phase (from phase  $p$  to phase  $p+1$ ). As mentioned, we measured participants' theory-of-mind skills, technical-reasoning skills and prosocialness in an attempt to predict the participants' attraction score at each phase (e.g., were some participants attractors within their group because they had high theory-of-mind skills?). The influence of these three predictors on the attraction score was tested using a Linear Mixed Model (LMM) with Chain number and Age as random effects. We found that only technical-reasoning skills were a predictor of attraction score with a clear tendency to significance at phase 2→phase 3 (i.e.,  $A(X)_{2 \rightarrow 3}$ ) and significant at phase 3→phase 4 (i.e.,  $A(X)_{3 \rightarrow 4}$ ; **Figure 5**; for best models and full-averaged models, see **Supplementary Material: Tables S1 and S2**). In other words, the higher a participant's technical-reasoning skills, the more the other members of the group tended to produce a tower similar to that participant at phases 3 and 4 (i.e., this participant became an attractor within the group). Participants may have needed time to identify a potential attractor within the group, explaining the absence of a significant influence of technical-reasoning skills at phase 1→phase 2 (i.e.,  $A(X)_{1 \rightarrow 2}$ ). The diffusion of the solution produced by the key attractor at building phases 1, 2 and 3 could have led many members to copy with fidelity their solution at phases 4, 5 and 6, reducing the possibility to identify specific individuals as attractors at the end of the experiment (i.e., for  $A(X)_{4 \rightarrow 5}$  and  $A(X)_{5 \rightarrow 6}$ ) because the most effective solution was already widespread over the group.

< INSERT FIGURE 5 ABOUT HERE >

We were also interested in examining which of the three aforementioned factors (or a combination thereof) was the best predictor of tower height. The influence of the three predictors on tower height was tested using a LMM with Chain number and Age as random effects. We

found that technical-reasoning skills were a significant or slightly significant predictor of tower height at phases 2, 3, 4 and 5 (**Figure 5**; for best models and full-averaged models, see **Supplementary Material: Tables S3 and S4**). Prosocialness was also a predictor of tower height with a favorable statistical trend at building phases 3 and 4. These results indicate that good engineers were the most successful, explaining why they were also preferential attractors (see above). Their ability to keep on making the highest towers may suggest that they were able to extract relevant information from the other members of the group to improve their solution. Another possibility is that they were able to make higher towers merely based on their previous attempts.

A potential limitation of our experiment is that our task was not an open-ended problem (i.e., with multiple potential solutions) but a close-ended problem (i.e., with only one solution). In other words, if only one solution allowed participants to build high towers, they could have progressively found this solution by themselves over the experiment. In this context, participants with high technical-reasoning skills could have produced this effective solution in the very first attempts and those with low technical-reasoning skills later, generating the illusion that participants with low technical-reasoning skills used those with high technical-reasoning skills as models. The analysis conducted on mean similarity already rules out this possibility, indicating the emergence of cultural lineages over the experiment, which contradicts the idea of a convergence toward a unique effective solution. Nevertheless, we scrutinized the proportion of the different tower shapes built by participants at the 6<sup>th</sup> attempt (i.e., Tower n°6), where the convergence toward a unique solution was more likely to occur. As shown in **Table 1**, participants in both experimental and control groups produced a great variety of different towers. More interestingly, we observed that eight out of the 16 possible tower shapes reached a mean

height of more than 30 cm (**Table 1**). These results clearly exclude the possibility that the attraction of participants with high technical-reasoning skills was illusory because of a convergence effect.

< INSERT TABLE 1 ABOUT HERE >

### **Discussion**

Here we offer an original insight into the question “From whom do we learn?” in a technological context. We learn from people with high technical-reasoning skills (i.e., engineers), simply because they are the most successful for a technical task, confirming the “copy the most successful individuals” strategy hypothesis (Henrich and Broesch 2011; Henrich and Gil-White 2001). The attraction power of engineers is not immediate but, after they have been identified as attractors, their technique is copied irrespective of their degree of pedagogy or prosocialness. This gives us an interesting picture of how people learn from each other, thereby complementing experimental and modeling works investigating the who-strategy issue (Efferson et al. 2008; Mesoudi 2008; Mesoudi and O’Brien 2008; Morgan et al. 2012; Muthukrishna et al. 2014). Our empirical findings open new avenues for the study of social learning strategies, which we will discuss below in more detail.

The first avenue concerns the role of pedagogy/theory-of-mind skills. We found that these skills had no influence, neither on attraction, nor on the quality of the solution. However, these findings do not rule out the importance of theory of mind in social transmission. Instead, they indicate that when people have to select a potential model, success takes priority over easiness of transmitting information (i.e., pedagogy). In a way, people may be ready to invest effort to understand how most successful individuals manage to produce effective artifacts, even when they are limited to transmit their knowledge in a pedagogical way. This also supposes that we do

not need to excel in our certainly uniquely human pedagogical skills to learn from our conspecifics, which is relatively adaptive when a solution to a new problem has to be created and spread. The present study precisely investigated this situation. The task was unfamiliar and participants had to come up with potential solutions. Nevertheless, the height of towers could reach an asymptote after several other attempts, revealing difficulties to improve the solution chosen. In this case, that is, when the solution becomes relatively stable among the different members of the group, it remains likely that pedagogues could become greater attractors because of their ability to easily transmit the building technique. Our study did not investigate the role of theory-of-mind skills, technical-reasoning skills and prosocialness in such a context (i.e., when a technique is stabilized). This may be an interesting study whose results taken together with ours might offer a new way of understanding the role of theory of mind in the social transmission of technological content. Importantly, an alternative interpretation is that some factors not explored here could have masked the potential role of theory-of-mind skills (this limitation also concerns our interpretations on the impact of prosocialness). Evidence has shown that individuals can be copied or ignored as a function of their dominance (e.g., Cook et al. 2014). Thus, even participants with high theory-of-mind skills could have been not copied because of their dominance. Future research is needed to examine this viable interpretation, for instance, by collecting the content of discussions during discussion rounds. Finally, theory-of-mind skills were determined here through separate tests in the individual testing session. This does not guarantee that participants with high theory-of-mind skills actually showcased their skills in the main experiment. Future work is also needed to overcome this potential methodological limitation.

The second avenue concerns the key importance of technical reasoning not only as source of attraction but also of performance. This is consistent with several recent studies that have

stressed that learners' ability to extract relevant information from a model (e.g., seeing that a model builds a tower with convergent feet, that is, a very effective solution) might play a role in social transmission (Zwirner and Thornton 2015; see also Vaesen 2012). Our results clearly support this proposal. The best engineers were able to constantly improve their artifacts. They were preferentially copied, irrespective of their theory-of-mind skills or degree of prosocialness. We also found that their influence takes place at the beginning/middle but not at the end of the experiment, because of the progressive diffusion of their technique, which is progressively shared by most of the members of the group. These findings are consistent with evidence from developmental and animal literature that indicate that children, adults but also nonhuman animals might copy the most knowledgeable individuals (see Kendal et al. 2015; Ottoni et al. 2005; see also Jimenez and Mesoudi 2019; Price et al. 2017). This is also consistent with the prestige theory of cultural transmission in that the prestige based-attraction is an emergent process, which is then replaced by a popularity/conformism mechanism (Henrich and Broesch 2011; Henrich and Gil-White 2001; for discussion about the link between prestige and competence, see Jimenez and Mesoudi 2019). However, the reference made here to prestige has to be taken with caution, because we did not collect any data indicating that our participants have exhibited deference behavior (a necessary characteristic of prestige) toward those with high technical-reasoning skills. In broad terms, technical-reasoning skills might play a critical role in the social transmission of technology and in the social learning strategies followed by individuals (Osiurak and Reynaud in press). Nevertheless, much more work is obviously needed to generalize this conclusion to any technological context, particularly in the case where the building process of an artifact to be transmitted is opaque and not transparent as in the present experiment. In addition, our failure to reproduce cumulative technological culture in our study (for discussion on this

aspect, see below) raises the question as to whether the copy the engineer strategy is relevant in a truly cumulative context.

The third avenue concerns the involvement of prosocialness in social transmission. Our study reveals that prosocial people are not those who are preferentially copied, stressing that, when the time comes to decide which individual to copy, success takes priority over friendliness. However, our study emphasizes that prosocial individuals might contribute at the middle/end of the experiment to the diffusion of the technique generated by good engineers. This might correspond to the manifestation of collaborative engagement, allowing the whole group to improve over time. This conclusion has to be taken very cautiously as it is based on results, which are close to significance but, nevertheless, not significant. Future research is clearly needed to explore further this aspect, perhaps by collecting data directly from the experiment (e.g., analyzing the group dynamics and the content of what is said during the discussion phases) in order to confirm that our measures of prosocialness really revealed prosocial behavior during the experiment. If the statistical trend obtained here comes to be confirmed in other works, this could raise the question about the optimal proportion of good engineers/friends in order to obtain the most effective cumulative evolution. Is it better to have a group consisting only of good engineers or a group consisting of an extremely good engineer with friends? Our findings seem to indicate that the latter option is potentially more advantageous. This exciting question deserves future investigation through both empirical and modeling work.

The fourth avenue concerns the difficulty for the experimental group to outperform the control group, which is at odds with previous evidence of cumulative performance in micro-society paradigms. In broad terms, we failed to reproduce cumulative technological culture, raising the issue of the implication of our findings for understanding the origins of this phenomenon (see Mesoudi and Thornton 2018). The most obvious reason of this failure is

certainly that the tower task was not complex and difficult enough, a methodological limitation frequently found in the literature (see Miton and Charbonneau 2018). In the next sections, we discuss other potential reasons for our failure to reproduce cumulative technological culture.

To explore the who-strategy issue, we created a closed-group paradigm, in which participants could exchange information verbally, without any material. This diverges from previous studies where models are imposed by the experimenter. In this way, it could be hypothesized that it is not an easy task for people to decide which individual to copy particularly when anyone can be a potential model. In addition, people do not necessarily copy entirely what a model proposes but can also be inspired by different models. In the present experiment, we found that people with high technical-reasoning skills exhibit the greatest attraction within their group. This implies that they were a source of inspiration for the other members of the group even if our data did not allow us to rule out the possibility that other participants copied their entire production and were not inspired, perhaps to a lesser extent, by other members of their group. A recent study indicated that cumulative technological culture preferentially occurs in a one-model condition rather than in two- or four-model conditions (Fay et al. 2019; see also Caldwell and Millen 2010). This finding suggests that the presence of a great number of models might overwhelm individuals' attentional/working-memory capacity, preventing them from extracting from the different models the potential relevant information useful for improving their artifact (see Fay et al. 2019). This interpretation in terms of attentional/working memory can however not explain our failure to reproduce cumulative technological culture given that our participants were able to select the most successful models, namely, those with high technical-reasoning skills. Further work is needed to explore this aspect.

Another potential reason for our failure to reproduce cumulative technological culture might be that our participant groups consisted of strangers who had no explicit information about

who in their group ranked high in terms of theory of mind, technical reasoning or prosocialness. Such explicit information could have helped them to detect more easily the model to copy based on their own social learning strategies (Heyes 2016; Shea et al. 2014). This possibility deserves to be explored in a future study, in which participants could be close peers and not strangers. Regardless, our paradigm remains largely ecologically valid because, in everyday life, we access the level of theory of mind, technical reasoning, and prosocialness of our conspecifics by interacting with them and not by knowing their scores on standard tests (for other studies in which no explicit information is given to participants about models, see Chudek et al. 2012; Flynn and Whiten 2012). The fact that participants with high technical-reasoning skills became attractors only from the middle of the experiment also confirms this proposal. Indeed, this can suggest that participants progressively built a “representation” of other participants’ cognitive skills as if they were informed *a priori* about these features. In this way, the present study offers an original contribution to the literature, stressing that social learning strategies can also emerge without information explicitly provided by the experimenter. The outstanding issue is whether the social learning strategies followed by the participants were conscious or not (Heyes 2016; Shea et al. 2014). This aspect, which was not addressed here, deserves attention in future research.

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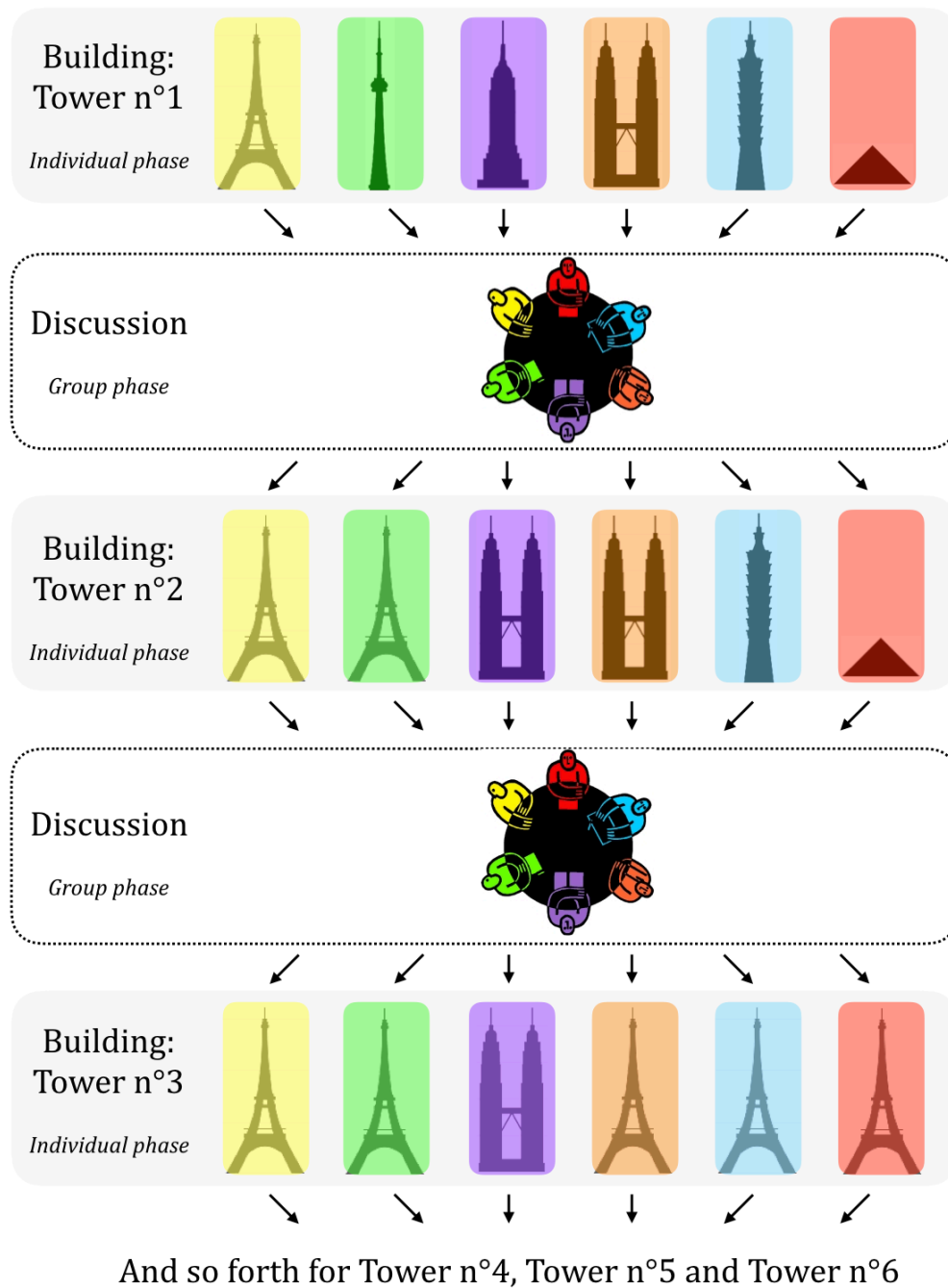
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*Figure 1.* Closed-group micro-society paradigm used in the present study. In this paradigm, participants began with an individual building phase (4 min long), where they built a tower without communicating or observing the other members of the group (Building phase: Tower n°1). Then, they were gathered to discuss the best solutions to increase tower height (4 min long). After this discussion phase, they had to make a new building attempt, again individually (Building phase: Tower n°2), followed by another discussion phase, and so forth for a total of six building phases and five discussion rounds.

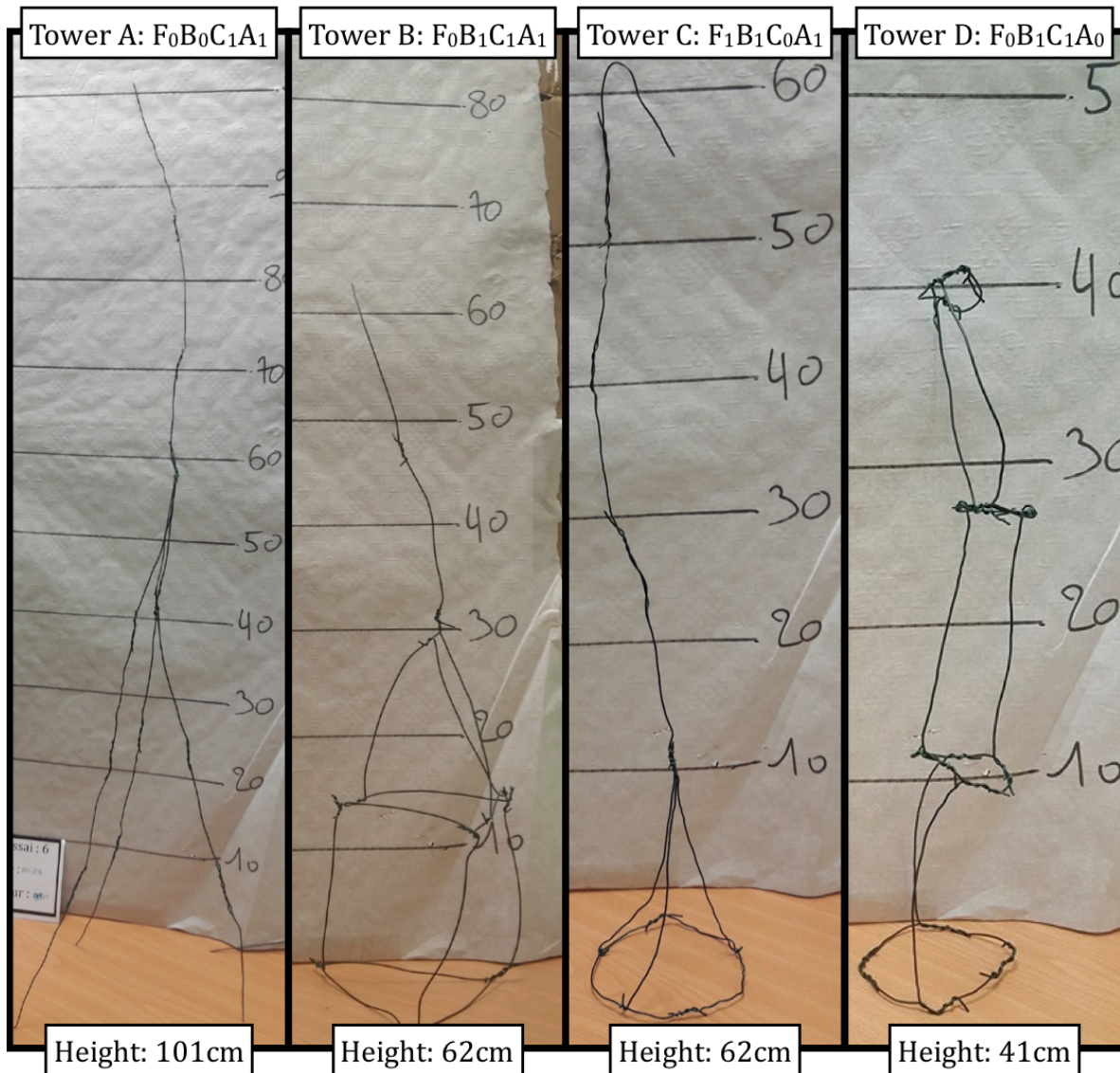


Figure 2. Pictures of towers produced by participants (Tower n°6) illustrating the coding system for the tower shape. Four features were used to characterize the towers. *Convergence of feet* ( $F$ : 1=Yes, 0=No): Feet were considered as convergent if the first vertical wires were directly connected together without the layer of additional wires before the junction as illustrated by Tower C. Note that one may think that Tower A also falls into this category because the feet are not strictly parallel. However, two additional vertical wires were added by the participant before the junction. *Presence of a basis* ( $B$ : 1=Yes, 0=No): We considered that a basis was present if at least two wires were connected together and added at the basis of the feet as illustrated by Towers B, C, and D. *Presence of intermediary columns* ( $C$ : 1=Yes, 0=No): We considered the presence of a column if at least two wires were added to the feet without being connected together vertically as illustrated by Towers A, B, and D. *Presence of an antenna* ( $A$ : 1=Yes, 0=No): We considered that an antenna was present if one wire or a series of wires connected together vertically were added on the top of the tower as illustrated by Towers A, B, and C.

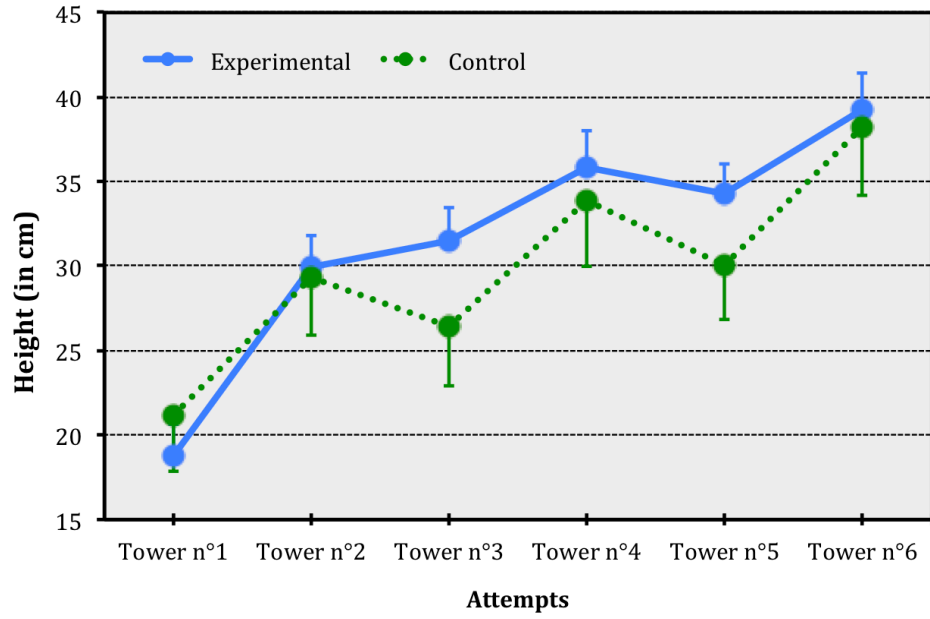


Figure 3. Tower height in both experimental and control groups. Bars represent standard errors.



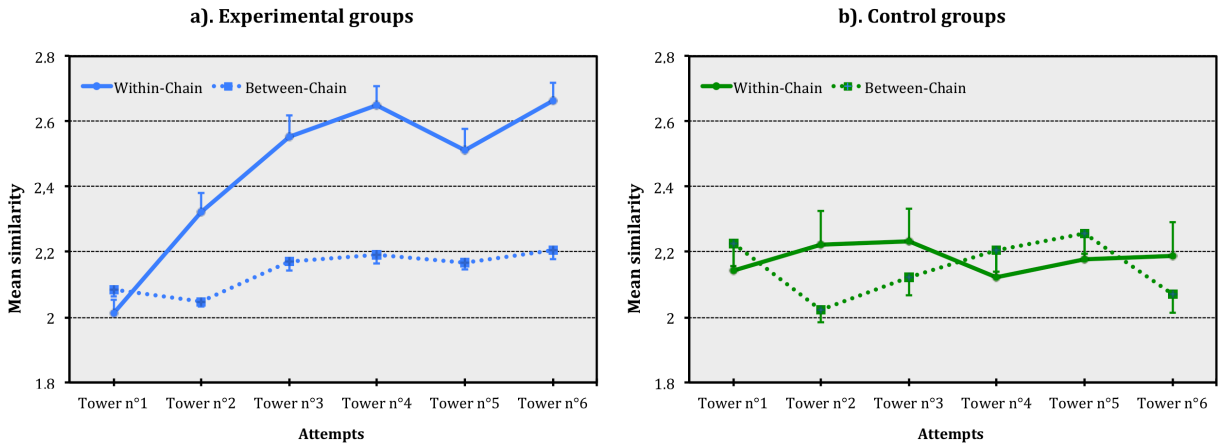


Figure 4. Mean within-chain and between-chain similarity in both experimental and control groups over the experiment. Bars represent standard errors.

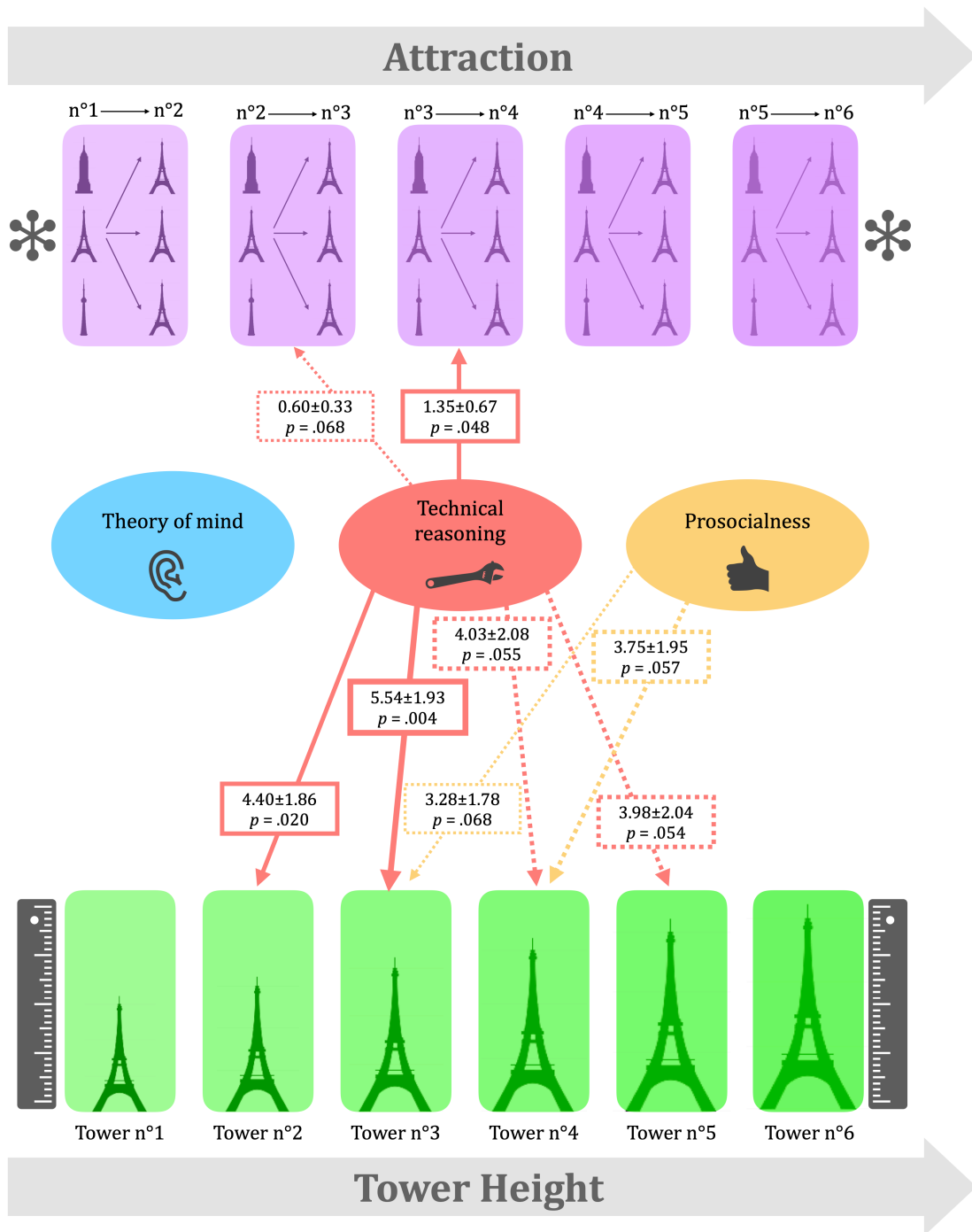


Figure 5. Factors predicting attraction and tower height over the experiment. Attraction was predicted only by technical-reasoning skills for phase 2→phase 3 and phase 3→phase 4. Tower height was predicted by technical-reasoning skills at phases 2, 3, 4 and 5, and by prosocialness at phases 3, 4 and 5.

Table 1  
*Percentage of participants and tower height for the 16 possible tower shapes in both experimental and control groups (Tower n°6 only)*

| Tower shape             | F <sub>0</sub> B <sub>0</sub> C <sub>0</sub> A <sub>0</sub> | F <sub>0</sub> B <sub>0</sub> C <sub>0</sub> A <sub>1</sub> | F <sub>0</sub> B <sub>0</sub> C <sub>1</sub> A <sub>0</sub> | F <sub>0</sub> B <sub>0</sub> C <sub>1</sub> A <sub>1</sub> | F <sub>0</sub> B <sub>1</sub> C <sub>0</sub> A <sub>0</sub> | F <sub>0</sub> B <sub>1</sub> C <sub>0</sub> A <sub>1</sub> | F <sub>0</sub> B <sub>1</sub> C <sub>1</sub> A <sub>0</sub> | F <sub>0</sub> B <sub>1</sub> C <sub>1</sub> A <sub>1</sub> |
|-------------------------|---|---|---|---|---|---|---|---|
| <i>Percentage</i>       |   |   |   |   |   |   |   |   |
| Experimental            | 0   | 0   | 4   | 10  | 1   | 3   | 14  | 24  |
| Control                 | 0   | 0   | 3   | 0   | 0   | 0   | 14  | 11  |
| <i>Height (in cm)</i>   |   |   |   |   |   |   |   |   |
| Experimental: Mean (SE) | ---   | ---   | 18 (2)  | 49 (3)  | 17 (-)  | 20 (2)  | 28 (1)  | 45 (2)  |
| Control: Mean (SE)      | ---   | ---   | 2 (-)   | ---   | ---   | ---   | 36 (1)  | 55 (3)  |

| Tower shape             | F <sub>1</sub> B <sub>0</sub> C <sub>0</sub> A <sub>0</sub> | F <sub>1</sub> B <sub>0</sub> C <sub>0</sub> A <sub>1</sub> | F <sub>1</sub> B <sub>0</sub> C <sub>1</sub> A <sub>0</sub> | F <sub>1</sub> B <sub>0</sub> C <sub>1</sub> A <sub>1</sub> | F <sub>1</sub> B <sub>1</sub> C <sub>0</sub> A <sub>0</sub> | F <sub>1</sub> B <sub>1</sub> C <sub>0</sub> A <sub>1</sub> | F <sub>1</sub> B <sub>1</sub> C <sub>1</sub> A <sub>0</sub> | F <sub>1</sub> B <sub>1</sub> C <sub>1</sub> A <sub>1</sub> |
|-------------------------|---|---|---|---|---|---|---|---|
| <i>Percentage</i>       |   |   |   |   |   |   |   |   |
| Experimental            | 0   | 11  | 3   | 10  | 2   | 13  | 1   | 5   |
| Control                 | 11  | 28  | 3   | 8   | 3   | 11  | 3   | 6   |
| <i>Height (in cm)</i>   |   |   |   |   |   |   |   |   |
| Experimental: Mean (SE) | ---   | 45 (2)  | 46 (1)  | 48 (2)  | 5 (1)   | 37 (2)  | 24 (-)  | 38 (2)  |
| Control: Mean (SE)      | 2 (1)   | 51 (3)  | 12 (-)  | 51 (5)  | 12 (-)  | 37 (4)  | 27 (-)  | 51  |

Tower shape: Convergence of feet, F<sub>0</sub>=No, F<sub>1</sub>=Yes; Presence of a base, B<sub>0</sub>=No, B<sub>1</sub>=Yes; Presence of intermediary columns, C<sub>0</sub>=No, C<sub>1</sub>=Yes; Presence of an antenna, A<sub>0</sub>=No, A<sub>1</sub>=Yes; SE, standard errors; (-), no standard error because the mean is based on only one participant.