**Intuitive Archeology in childhood: Detecting social transmission in the design of artifacts**

# 1. Overview

Children grow up surrounded by human-made objects (artifacts). These artifacts are useful not only as tools, but also as a constant source of social information, telling observers about the traits and social identities of people who own them, choose them, or create them. Adults appear skilled at reasoning about people based on the features of their objects, and in doing so, engage in a unique combination of social and physical reasoning -- a type of reasoning we term ‘intuitive archeology’. The current proposal aims to characterize the developmental trajectory and cognitive bases of this intuitive archeological reasoning.

Ideas for artifact designs come from two possible sources: They may be *generated independently* by an individual (i.e. generating a novel feature by insight, to solve a problem), or they may be *socially transmitted*. Such social transmission allows for the passing along or inheritance of ideas from one person to the next -- through social learning, or imitation of ideas from others. The combination of these two processes -- innovation and imitation -- together are used to explain cultural evolution, including how artifact features are generated, and how artifact features evolve over time (Mesoudi, Whiten, & Laland, 2004; Smith, Kalish, Griffiths & Lewandowsky, 2008; Legare & Nielsen, 2015; Tomasello, 1999).

Reasoning about people from artifacts thus fundamentally involves inferring when social transmission of ideas has occurred, as designs that were socially transmitted will be informative about their designers’ social history, and features which have been independently designed will not, instead leading to different inferences (e.g. about the nature of the problem, or the intelligence of the designer). Thus, accurately deriving social information from artifacts fundamentally requires rich, structured reasoning about the role of social transmission in the origin of particular features of an artifact.How does this complex reasoning develop in childhood? **Are children able to perform complex, structured reasoning when deriving social information from objects? Or do children use simpler heuristics, based on low-level features and perceptual similarity?**

To address this issue, we propose to characterize children’s reasoning about social transmission of ideas from artifact features, and tease apart two alternative accounts of the cognitive processes underlying conclusions about social transmission from artifacts - *explanation-based reasoning* vs. *perceptual heuristics*. We employ a task which allows us to systematically tease apart the predictions of these accounts:The case of observing two similar artifacts, created by different individuals, and being asked to explain their similarity. We ask: When do children and adults infer that social transmission of ideas has occurred? By systematically manipulating features of the artifact and of the context, we aim to tease apart the following two cognitive accounts:

***Explanation-based reasoning.*** We hypothesize that children will draw conclusions about social transmission through explanation-based reasoning, as an inference to the best explanation (Lipton, 2004; Tenenbaum et al. 2006). Under this account, to explain observed data (e.g. two people have created identical artifacts), we consider multiple hypotheses, then choose the hypothesis that offers the best and most likely explanation (e.g. they copied one another). This type of inferential reasoning occurs in childhood in multiple related domains, including causal induction and reasoning about others’ mental states (Teglas et al, 2011; Baker et al. 2008, 2009). This account makes specific predictions. Children should infer that social transmission has occurred when people create similar artifacts; but should not treat all similar perceptual features as equally strong evidence of copying. If an alternative explanation for the similarity is given, such as a functional constraint (the creators needed to solve the same problem) or an availability constraint (the creators had only a limited set of options), participants should no longer infer that creating the same artifact indicates that social transmission has occurred.

***Perceptual heuristic account.***Alternatively, children may use similarity-based heuristics, for instance by noting the perceptual similarity between the artifacts people have created, and assuming that any similarity implies that the ideas were socially transmitted. In this case, we should see specific, revealing errors when conceptual information conflicts with perceptual similarity. If children are using heuristics, providing an alternative explanation for the common features should have little or no effect; children should continue to conclude that the creators of similar artifacts have copied one another. Specifically: (1) If children fail to take into account functional constraints, then when we present artifacts that are perceptually similar but could have been created independently to solve the same problem, children should continue to infer that the ideas were copied. (2) If children fail to take into account availability constraints, then when we present artifacts that are perceptually similar but were the only possible option given the available choices, children should continue to infer that the ideas were copied.

To tease apart this perceptual heuristic account from explanation-based reasoning, we will conduct a collaborative research plan, involving computational modeling and behavioral testing in preschool children, school-age children and adults to understand how people reason about the role of social transmission in creating new artifacts:

**The first aim of the current proposal is to develop a formal Bayesian model of explanation-based artifact generation and inference**, and contrast it with a formal model of the simpler, perceptual similarity based account. In particular, we focus our efforts on modeling the core inference in this domain: Whether artifact designs were generated through social transmission (imitation), or generated independently. In particular, given two objects that are similar but were created by different individuals, when do people infer social transmission of information to explain their similarity (e.g., person 2 copied person 1)? We will formalize the two factors underlying artifact generation (socially transmitted ideas + independently generated ideas). By providing two ways of generating the same features of an artifact, the model predicts that people should “explain away” some aspects of similarity between artifacts. In particular, the model identifies two core ways in which explanation-based reasoning should reduce inferences of social transmission: similarity between features that are functional for solving the problem posed should not provide evidence of social transmission (*functional constraints)* and the number of available options for a given artifact-design situation affect how much explaining away should occur based on how likely the two artifacts are to be independently designed (*availability constraints*). Based on the modeling, we thus make use of these two constraints to tease apart the cognitive theories in the remainder of the proposal.

**In a second and third aim, we distinguish explanation-based reasoning from a perceptual heuristic account with experimental evidence from children and adults**, asking which better predicts how children of each age and adults reason about the social origins of artifacts. We use the constraints implied by the model -- *functional constraints* and *availability constraints* -- and ask if adults and children make use of these as alternative explanations. In other words, if one of these constraints implies alternative explanation for the similarity of two artifacts, do adults and children use this to “explain away” the similarity, and thus not infer social transmission? In Aim 2, we use a 2x2 design manipulating a functional constraint (how many artifacts could possibly be used to solve the task) and an availability bias (the number of options available for people in constructing the artifacts) implied by the model in a tool selection task. In Aim 3, we again use a 2x2 design to manipulate these same constraints, but in a new train track building task, and in qualitatively distinct ways, providing an independent window into the use of a functional constraint (how much people expect efficiency in artifact construction), and an availability constraint (presence of a barrier that limits options for artifact construction) as an explanation for similarity. The two aims thus provide two independent views on the extent of children and adults’ explanation-based reasoning.

This proposal will thus provide answers to fundamental questions about the nature of children’s reasoning in early development, and the extent to which they are driven by surface features or deeper, essentialized concepts. This broad theoretical argument dates back to Jean Piaget’s seminal work in cognitive development, and continues to the current day (for early deeper concepts: Gelman, 2003; Gopnik, 2012; Carey, 2011; for the primacy of perceptual features: Jones & Smith, 1993; Sloutsky, Kloos & Fisher, 2007). The proposal will introduce new behavioral and computational modeling methods designed to make specific predictions about when artifacts will trigger specific social inferences about social history and social transmission, and make explicit the reasoning processes involved in these intuitive inferences. The experiments and model each provide independent windows into children’s and adults’ reasoning processes about the origins of artifacts. The proposal includes an initial model with model results, as well as pilot data on the behavioral aspects of each task with adults and on relevant aspects of the tasks with preschool children, which provide evidence that the basic designs of the tasks are promising for investigating the social origins of artifacts. Overall, the proposal will provide insight into the richness of children’s reasoning about the social history of people from their objects, an important avenue for children to learn about others.

# 2. Theoretical Background

## 2.1 Artifacts as sources of social information

Children grow up in environments saturated by human-made objects. These artifacts differ fundamentally from natural objects like rocks and trees: Their properties are intentionally designed, often for a specific purpose (Kelemen & Carey, 2007). Reasoning about artifacts has enormous practical consequences, as effective use of artifacts as tools is necessary to function in any human society-- and has been crucial to human survival and evolution for hundreds of thousands of years (Gibson & Ingold, 1995).

From a theoretical standpoint, artifacts present a complex cognitive problem. Artifact reasoning requires inferring the intentions and goals of the artifacts’ creator, as well as the physical affordances of materials and causal reasoning about effects. Nevertheless, reasoning about the functions of artifacts develops surprisingly early: From preschool age, children categorize and label artifacts by their intended function rather than perceptual similarity (Kelemen, 1999; Trauble & Pauen, 2007; Booth & Waxman, 2002; Kemler-Nelson et al 1995), and recognize which physical properties contribute to a tool’s functionality, and which do not (Kemler-Nelson et al. 1995; DiYanni & Kelemen, 2008; Kelemen et al. 2012). Thus, an extensive literature has explored the development of reasoning about the functions and uses of these human-made objects.

However, artifacts are crucial to our lives not only as tools, but also as an ever-present *source of social information*. Based solely on the artifacts a person owns, adults form quick and accurate judgments about a person’s traits, interests, and social affiliations (Gosling, 2008; Richins, 1994). A vast literature confirms that adults choose and display artifacts as social signals, and interpret the artifacts of others as essential cues to their identity (Kleine et al. 1995; Ferraro et al. 2010; Solomon, 1983; McCracken, 1986; Belk, 1988). In addition, the artifacts adults *create* may hold the most social information -- creations like visual art, music, or written text provide rich information about traits, beliefs, and identity (Gosling, 2008). Thus, social cues from artifacts likely serve as implicit social glue, providing a foundation for smooth social interaction by providing information about other’s social history and social identity.

Understanding the social world is one of the most important challenges of early cognitive development (Tomasello, 1995). Social cognition and social relationships form a foundation for learning of everything from language (Bloom, 2000) to causal induction (Bonawitz et al. 2011), and failure to understand one’s social environment, as in the case of Autism Spectrum Disorder (ASD), leads to significant impairments in multiple domains of life (Frith, 2008). However, in spite of the significant role artifacts play in providing social information in adulthood, the cognitive and developmental bases of artifact-based social reasoning remain unexplored. Is sophisticated social reasoning from artifacts available to support social decisions in early childhood? Do children make specific social inferences based on the features of others’ artifacts? Answering these questions is a clear next step in characterizing social cognitive development.

**2.2 Detecting social transmission: A core inference in this domain**

Artifacts can provide multiple kinds of information about their creators as well as about their owners: Regarding the creator’s level of skill or intelligence (Gosling, 2008), or regarding the creator’s goals (Kelemen, 1999; Trauble & Pauen, 2007; Booth & Waxman, 2002; Kemler-Nelson et al 1995). One kind of social information that may be available in artifacts, and may be particularly important, is reasoning about social history.

Ideas for artifact designs come from two possible sources: They may be *generated independently* by an individual (i.e. generating a novel feature by insight, to solve a problem), or they may be *socially transmitted*. Such social transmission allows for the passing along or inheritance of ideas from one person to the next -- through social learning, or imitation of ideas from others. The combination of these two processes -- innovation and imitation -- together are used to explain cultural evolution, including how artifact features are generated, and how artifact features evolve over time (Mesoudi, Whiten, & Laland, 2004; Smith, Kalish, Griffiths & Lewandowsky, 2008; Legare & Nielsen, 2015; Tomasello, 1999).

Reasoning about people from artifacts thus fundamentally involves inferring when social transmission of ideas has occurred, as designs that were socially transmitted will be informative about their designers’ social history -- and features which have been independently designed will not, instead leading to different inferences (e.g. about the nature of the problem, or the intelligence of the designer). Reasoning about social transmission serves as the foundation for further inferences about important social properties, such as a person’s likely social and cultural group membership. For instance, if you and another person sing the same song (an auditory artifact), this is unlikely to occur by chance: there are so many possible songs that it is unlikely that two identical songs have been independently derived. Instead, the information is likely to have been socially transmitted, strongly implying that you and the other person share some social history, such as a common cultural group. Preschool age children have been shown to make such inferences about social group from musical knowledge (Soley & Spelke, 2016), consistent with the idea that children may use inferences about social transmission to derive socio-cultural information.

Thus, at the core of making intuitive archaeological inferences like this is the ability to detect features that are likely to have been socially transmitted, and distinguish them from features that may have been generated independently, without social transmission.How does this complex reasoning develop in childhood? Are children able to perform complex, structured reasoning when deriving social information from objects? Or do children use simpler heuristics, based on low-level features and perceptual similarity?

Scholars of cognitive development have characterized children as little scientists, constructing, testing, and refining intuitive mental theories of different domains. For instance, children develop intuitive mental theories of physics (Carey & Spelke, 1994; Baillargeon, Spelke & Wasserman, 1985), intuitive theories of psychology (Woodward, 1998; Wimmer & Perner, 1983; Baron-Cohen, Leslie & Frith, 1985); and intuitive theories of biology (Carey, 1985; Inagaki & Hatano, 2002; Coley et al, 2002). Here we propose and test the structure of a new domain of intuitive reasoning: intuitive archaeology. Just like archaeologists use inanimate objects to infer social information about the people and cultures that created them, children may intuitively engage in similar kinds of intuitive reasoning, combining their understanding of the physical world (how tools work, physically) with their understanding of the social world (understanding of others’ preferences, goals, knowledge-states, and beliefs), to pull complex social information out of the design of objects.

# 3. Aim 1: A Generative Bayesian model of explanation-based reasoning about artifacts

## 3.1 Introduction to the modeling approach

The first goal of the current proposal is to develop a formal model of how adults and children reason about social information in artifacts, in order to test and tease apart two cognitive accounts of the reasoning processes. In particular, we will develop the formal tools to ask: Is intuitive archaeological reasoning a type of rational inference, over rich and structured mental representations, as proposed by our *explanation-based reasoning account*? Or is it captured by simpler associative reasoning and perceptual-based representations, as proposed by our *perceptual heuristic account*? Does children’s early reasoning rely on perceptual features, becoming more complex only later in development?

To develop a model of *explanation-based reasoning* for intuitive archeology, we must first ask: How are artifacts generated? If we can specify a generative model of artifact features, then we can make precise predictions about how people will reason about the origins of items generated from that process, including the likelihood of social transmission of ideas. This will allow us to dissociate the predictions of a simple perceptual model from those of an explanation-based inference, and (in Aim 2 and 3) ask which of the two models best captures children’s and adults’ judgements and reasoning.

The broad idea of the model is thus to consider the two possible generative processes of an artifact’s design (social transmission of ideas vs. independent creation of ideas) and then ask which provides a better explanation of the features of a given artifact. Given this generative structure, independent creation can “explain away” some aspects of the similarity between artifacts in certain circumstances, reducing the likelihood of inferring social transmission. Thus, broadly speaking, an artifact-generation model has a similar structure to the application of Bayes nets in the literature on how children learn about causal structure. For example, in Gopnik and Sobel’s (2000) classic blicket detector paradigm, children are presented with a number of blocks as well as a “blicket detector” - a machine that lights up when certain blocks (termed “blickets”) are placed on it. However, children do not know in advance which blocks are blickets, and must determine this from observations of the machine. The most interesting case of causal learning in this scenario is termed *backward blocking* (e.g., Sobel, Tenenbaum & Gopnik, 2004) - in this scenario, children observe two blocks placed on the machine simultaneously, and the machine lights up. Having observed this, children commonly infer that both blocks are blickets. On the next trial, one of the blocks is put on the machine alone, and the machine still lights up. Based on this, children not only infer that this block *is* a blicket, but also infer that the other block (from the previous demonstration) *was not* a blicket. This inference suggested that, rather than relying purely on associative structure (both blocks being associated purely with the machine lighting up), children are performing a more complex inference: Using the evidence that the second block is a blicket to “explain away” the first activation of the machine (as it would have activated even if the first block was not a blicket), thus weakening the evidence that the first block was a blicket.

This kind of inference is well-explained by the conditional probability structure of causal Bayes nets (Gopnik & Glymour, 2002; Sobel, Tenenbaum & Gopnik, 2004), where the causal structure is in the form of two possible causes and a single effect; observing the effect provides evidence for both causes, but if one is known to be true, this reduces the evidence for the other cause, assuming the causes are conditionally independent (e.g., Pearl, 2000). In the domain of causal reasoning, explicitly specifying the alternative models -- Bayesian learning over structured representations vs. associative reasoning -- has been extremely fruitful to understanding the nature and structure of underlying reasoning. Here, we propose an analogous model, following the same Bayes net structure of “explaining away” (with two causes leading to a single effect) to test the extent to which structured reasoning vs. purely perceptual reasoning is at work in children when considering the origins of artifacts.

## 3.2 Modeling a single choice design (tool selection task) as explanation-based reasoning

|  |
| --- |
|  |
| *Figure 1. Design of tool selection task. If two people pick the same rod, did they copy each other?* |

Imagine a scenario (described in detail below in 4.3 and 4.4) where you are asked to solve a puzzle: A button is out of reach in a box, with the front covered by glass, so only the hole in the top allows access. You must build a tool to reach the button, and are given a handle and choice of rods that can connect to it and make it reach the button (see Figure 1). In the case of one puzzle box, which has a circular hole, all of the 10 rods would fit through the box’s circular hole and solve the puzzle (*unconstrained; circle box)*. In the other case, the star shaped box, only 1 of the 10 rod options -- the **star** shape -- fits, and so only 1 of the 10 options will allow you to solve the puzzle (*constrained; star box*). This box thus introduces a functional constraint. Now, you observe the tools that other people have made: Two people built the exact same tool, by choosing the same star-shaped rod. How likely are they to have copied each other? Does this differ in the *constrained* and *unconstrained* case, even though the tools are equally perceptually similar in the two cases?

Framed mathematically, this can be understood as a Bayesian inference, where, if *c* indicates whether person 2 copied person 1, you wish to inferthe probability of copying *p(c),* given the observed object *o1* of person 1 and object *o2* of person 2. Broadly, you wish to make the following inference:

This is the posterior on copying: The probability that copying has occurred, given your prior likelihood on copying and the relative likelihoods that those designs would be generated under each of the possible mechanisms (copying vs. independent creation), where:

This gives the overall probability of object o2, under the process of copying and under the process of independent creation. To make this model concrete, we need to specify 3 things:

(1) *p(c)* - a priori estimate of how likely person 2 was to have copied (unconditional on the data; e.g., before we see either of the objects *o1*/*o2*); this will be set by the description of the scenario. For example, if person 1 is sitting next to person 2 and encouraged to collaborate, this might be close to 1.0. If person 1 and 2 are in different rooms with no way to see each other, it might be close to 0.0.

(2) *p(o2|c, t1)* - the likelihood of the particular features of object *o2* being generated, given that person 2 was in fact copying from person 1’s object (*o1*); This should place very high likelihood on *o2* being exactly like *o1*.

(3) p(o2|*c*) - the likelihood of object *o2* being generated given that person 2 was NOT copying from person 1’s object (*o1*), and independently generated the object with no reliance on *o1*. In the *unconstrained* condition, this should be 1/10 for any object, as all rods are equally useful to solving the task. In the *functionally constrained* condition, however, this should place very high probability on the **star** shaped rod, and very low probability on all the others.

Now imagine the scenario where 2 people make the exact same tool to solve the problem. If children base their belief about social transmission only on similarity between the objects, they should infer that the two people copied from each other to an equal extent across all conditions, since they have always made the same tool.

By contrast, the model of explanation-based reasoning predicts specific, quantitative differences between the constrained and unconstrained conditions, under a wide range of reasonable parameter settings. In the *unconstrained* condition, where any of the ten pieces would solve the puzzle, observing that person 1 made a star-shaped tool and then that person 2 also made a star-shaped tool gives a posterior on copying of = ~0.50 -- we think it is definitely possible they copied, about a 50/50 proposition. In other words, when the choice was *unconstrained*, two people picking the same star shape is a suspicious coincidence, and thus provides evidence that the design was generated through social transmission -- person 2 copied person 1. In contrast, in the *constrained condition*, observing 2 star-shaped tools provides no evidence of copying at all -- if we assume 95% of people will succeed at solving the problem, then our posterior of copying is only = 0.10, a 10% chance of copying each other. Thus, one aspect of explanation-based reasoning that is formalized by the model is that the likelihood of generating the same item independently (p(o2|*c*)) is affected by the limitations on what options will successfully solve the problem. We refer to this property of the model as a role for **functional constraints** - it predicts that more constrained problems will create higher likelihood of independently creating the same object, thus explaining away two artifacts’ similarity, and weakening the evidence of social transmission.

Similarly, the model of explanation-based reasoning predicts that the number of options available to participants should affect the likelihood of social transmission -- if only a single shape of rod is available, the probability of this choice under the independent generation model (p(o2|*c*)) goes to 1.0, as it is the only choice, and thus the evidence of copying weakens significantly. We refer to this property of the model as **availability constraints** - it predicts that having fewer options to choose from in creating an object increases the likelihood of independently creating the same object, thus explaining away two artifacts’ similarity and weakening the evidence of social transmission.

Thus, even in this simple one-choice scenario, we can contrast simple perceptual heuristics -- they have the same tool, so they may have copied each other -- with more explanation-based reasoning, formalized in a Bayesian model. This model allows us to make quantitative predictions to design experiments asking whether children “explain away” the similarity of the tools by reasoning about the generative processes used to build the tools to solve the task (see Aim 2), thus taking into account *functional constraints* and *availability constraints*.

**3.3 Modeling explanation-based reasoning about efficiency (train track building task)**

|  |
| --- |
|  |
| *Figure 2. Design of train track task. Did person 2 copy person 1?* |

The tool selection task involves a very straightforward decision - a single choice of which rod to pick, where in the *constrained* scenario only a single rod can achieve the goal. Can we generalize our model to more complex artifacts, where the functional success of a set of choices is graded rather than all or none? Does this reveal other independent aspects of *functional constraints* and *availability constraints* that can be experimentally tested?

To examine this, we model the case of a train track building task. The structure of this task is as follows (see Figure 2): Imagine you have a toy train track built by person 1, track *t*, and then you are shown a new track, *t2*, built by person 2. You wish to infer whether person 2 copied the track’s design from person 1 or independently created it.

Framed mathematically, you wish to infer the posterior on copying *p(c),* given the observed track *t1* of person 1 and track *t2* of person 2, along with two additional parameters that go beyond the single choice task of 3.2: *a*, the copying accuracy, and *f*, the efficiency preference. Thus, we wish to make the following inference:

With being the posterior probability on copying after we observe the tracks made by the two people, *t1* and *t2*. This once again has the structure of a Bayes net, with the key concept of explaining away -- a track can be generated either via copying or independently, and evidence for one provides evidence against the other -- so that particular tracks that are likely to be created independently provide less evidence for copying. To make this model fully concrete, we once again need to specify the prior (*p(c))* as well as two likelihoods:

1. *p(t2|c, t1, a)* - the likelihood of the particular track *t2*, given that person 2 was in fact copying person 1’s track (*t1*); and given a copying accuracy parameter (*a*). If copying has occurred, high copying accuracy (high values of *a*) should place high likelihood on *t2* being from the set of tracks most similar to *t1*, with the highest likelihood on *t2* being exactly like *t1*. Lower copying accuracy (*a*) should result in more variation. Graded copying accuracy captures the intuition that in a more complex design task like this train track task, there may be partial social transmission of ideas -- participants may be influenced by each other, while not making exactly the same track.
2. *p(t2|c, f)* - the likelihood of track *t2*, given that person 2 was NOT copying from person 1’s track (*t1*) and independently generated the track with no reliance on *t1*. This depends on *f*, the strength of the efficiency preference -- e.g., how likely people are to prefer short, efficient tracks that directly connect the goals. A high efficiency parameter (*f*) should place high likelihood on extremely short tracks, thus making certain highly efficient track designs highly likely even when the tracks were generated independently -- weakening the evidence of copying from certain perceptually identical tracks. This captures the intuition that in this scenario, participants may be more or less likely to prioritize getting from A to B efficiently, which will change the likelihoods of each track to occur independently and thus affect judgements of whether social transmission has occurred.

To formalize these likelihoods, we treat *a* and *e* as the slope of logistic function on similarity between tracks (for *a*) and on track length (for *f*). Thus,

Where dt1,t2 is the distance between track *t1* and *t2,* here modeled as the number of non-overlapping piece locations from the two tracks. Probabilities are normalized over the set of *t2’s.* Similarly:

Where Lt2 is the length of track *t2* (since all track options are required to get from A to B, shorter tracks are by definition more efficient). Probabilities are again normalized over the set of *t2’s[[1]](#footnote-1).* Given the way these functions are parameterized, larger positive values of *a* lead to a stronger copying accuracy (e.g., a steeper fall off in how likely a track is if it is more dissimilar to t1), and larger positive values of *f* provide a stronger efficiency preference (e.g., a steeper fall off in how likely people are to generate long tracks).

These functions capture the required aspects of the model -- that more efficient tracks are more likely to be independently generated, and copying is mostly without error -- and thus allow for a general set of predictions to be made about children’s judgments about social transmission (copying), if children are using *explanation-based reasoning*.

|  |
| --- |
|  |
| *Figure 3. Same tracks as figure 2, but with barriers. Does this seem less like copying?* |

In this model, we require a parameter, (*f*) that specifies how much we expect people to prioritize efficiency in track design (e.g., how strong their preference should be for short tracks). We can thus test sensitivity to a novel form of **functional constraint** in this model, independent from those observed in the tool creation task: Higher efficiency parameters result in more functional constraints. That is, higher efficiencies lead to a higher likelihood of independently creating the same (short and efficient) tracks. Thus, higher efficiency parameters -- and manipulations that make people expect higher efficiency in track building -- result in more “explaining away” of similarity, thus lowering the likelihood of social transmission.

Similarly, in this problem, we can easily contrast how many tracks are possible to build with the addition of barriers (see Figure 3). In the barrier case, a brick wall eliminates the option of many tracks that could otherwise be used to connect the two houses. Thus, the probability of the remaining tracks -- particularly the remaining shorter tracks -- goes significantly up in the independent generation model, p(o2|*c*)[[2]](#footnote-2). Thus, this is another different aspect of an **availability constraint** - with fewer options to choose from in creating an object, this increases the likelihood of independently creating the same object, thus explaining away more aspects of similarity and lowering the likelihood of social transmission.

The Bayesian model of the train track task thus allows us to directly contrast the extent to which children take into account the efficiency of an artifact’s design when considering the extent of social transmission. The model predicts that, for two identical tracks, people should infer that social transmission is more likely to have occurred when the two tracks are inefficient paths between the start and end point than when they are efficient paths, even when the tracks are perceptually identical in both cases. Thus, this model allows us to make quantitative predictions to tease apart our two theoretical accounts, asking whether children use similarity-based heuristics to reason about social transmission, or use explanation-based reasoning to “explain away” the similarity of the tracks based on their efficiency (see Aim 3).

## 3.4 Take-home points from the Bayesian model of explanation-based reasoning

The explanation-based reasoning model differs from the perceptual similarity model in that it takes into account alternative explanations for similarity, and uses them to “explain away” the similarity, leading to a low likelihood of copying for some artifacts with identical perceptual features. Formalizing this model indicates two important ways to affect the likelihood under the independent generation model, p(o2|*c*), and thus the overall posterior on how likely copying/social transmission is: *Functional constraints* and *availability constraints*. Our two proposed tasks reveal distinct ways these functional constraints and availability constraints can play a role: e.g., functional constraints can arise from both limits on which tools can achieve the goal (in the tool selection task) and from how strongly efficiency is prioritized (in the train track task); availability constraints can arise from how many ways are available to build an artifact (in the tool selection task) or from barriers or other constraints that limit the number of possible artifacts that can be constructed (in the train track task).

If children use an explanation-based model, each of these constraints should decrease their inferred likelihood of social transmission; if children use a simpler model based on perceptual similarity, these factors should not change children’s judgements. Thus, in the experimental parts of this proposal, we test the role of these two important constraints in distinguishing an explanation-based reasoning account from a more perceptual account. Broadly, we propose that a model with two possible ways of generating an artifacts’ features -- independent creation or social transmission -- can lead to rich and explanation-based inferences about the origins of artifacts that go significantly beyond perceptual similarity, by introducing the concept that some aspects of an artifacts’ similarity can be ‘explained away’ by a high likelihood of independent creation, thus reducing the evidence for social transmission.

# 4. Aim 2: Children’s reasoning about the social origins of artifacts in a single choice design

In Aim 2, we propose to characterize the developmental trajectory of children’s reasoning about social transmission of ideas on the basis of others’ artifacts, and tease apart the two potential alternative accounts of the cognitive processes underlying this reasoning that have been introduced and formalized in Aim 1 (e*xplanation-based reasoning* and *perceptual heuristics*).

Aim 2 focuses on the tool selection task, where only a single choice needs to be made -- and thus only a single choice needs to be explained as either based on social transmission or not. To tease apart the two models, we manipulate the factors identified in Aim 1 as critical to distinguishing the models - *functional constraints* and *availability constraints*. Here, we manipulate functional constraints by changing the nature of the problem (the puzzle-box), such that all, or only some, artifact designs can successfully achieve the goal. We manipulate availability constraints by manipulating the number of different pieces available for artifact construction, such that the piece is chosen from a set of many or few options. This set of experiments thus provides a direct window into whether, under simple circumstances, children can make use of explanation-based reasoning to draw conclusions about the origins of artifact designs, by using functional and availability constraints to explain away some aspects of a set of tools’ similarity.

We plan to test children of preschool and school age, along with adults. We hypothesize that while the youngest children may use perceptual similarity, children of preschool or early school age will draw conclusions about social transmission through explanation-based reasoning, as an inference to the best explanation (Lipton, 2004; Tenenbaum et al. 2006). Related types of inferential reasoning occurs in childhood in multiple related domains, including causal induction and reasoning about others’ mental states (Teglas et al, 2011; Baker et al. 2008, 2009), and some aspects of this reasoning are seen by 4 years of age in the related non-social causal learning literature (e.g., the blicket detector paradigm; Sobel, Tenenbaum & Griffiths, 2004). Thus, developmental change in the extent of explanation-based reasoning is likely in the early school years, our target age range.

## 4.1 Tool selection task

*Participants:* Adults and children. Based on a power analysis of our pilot data (see below), we plan to test children at age 4, 6 and 8 (100 participants at each age), as well as adults (18+ years), to probe for developmental change. We expect that children should be able to understand and perform this task by at least five years of age, and likely by age four: Methods similar to the current one have been validated in children as young as age 4 (Sobel, Tenenbaum, Griffiths, 2004), and by 5, children can identify the non-functional features of artifacts (Kelemen et al., 2012), and understand that ideas about artifact design can be socially transmitted (Olson & Shaw, 2011).

*Method* – Our first set of experiments will examine reasoning about social origins in the simplest generative case: Building a tool by making a single design choice, from a set of options. The basic structure of this task, as described in 3.2 above, is that two people (one of whom is the participant) are shown a puzzle box. Each one builds a tool to solve the puzzle -- and they end up creating the same tool. The question is: when do participants judge that the design was copied (thereby socially transmitted)? By varying the physical structure of the puzzle-box, we systematically vary the level of *functional constraint* on the tool -- in one condition (but not the other), only one of the available options can solve the puzzle. If children’s reasoning is primarily driven by perceptual similarity, then the level of functional constraint should have no effect on their answers: They should say identical tools were copied equally in both conditions. Alternatively, if children’s reasoning is rich and structured in the way posited by our explanation-based model, these functional constraints should be able to ‘explain away’ artifact similarity, making it only weak evidence of copying. That is, making the same artifact when the design was functionally constrained is not good evidence of social transmission of ideas, as both people could independently discover the same (and only) solution.

|  |
| --- |
|  |
| *Figure 4. Availability manipulation: 1 option vs. 10 options for the rod.* |

In addition, by varying the number of available options, we can provide an additional test: If the other person is selecting from a set of identical options (every available rod is star shaped), then creating the same tool is not good evidence of copying. Here there is a different alternative explanation for creating the same tool: an *availability constraint*, which gives another alternative way to ‘explain away’ similar design choices without inferring social transmission. Both of these cases provide tests of whether reasoning about social transmission is explanation-based, or driven by perceptual similarity alone. To tease apart these two accounts, we will thus provide two manipulations to provide alternative explanations: by changing the functional constraints (see Figure 1), and, orthogonally, by changing availability constraints (manipulating the number of distinct rods available as options, 1 vs. 10; see below; Figure 4).

*Logic:* Every adult participant will participate in each condition, including multiple trials each with a distinct set of stimuli. Due to constraints on executive function and memory in childhood, every child participant will participate in one condition, with multiple trials within that same condition. The order of conditions and pairing between stimuli and condition will be counterbalanced across participants. Stimuli will be normed through pilot testing to ensure that tools are seen as achieving the goal with equal ease in all conditions, using methods from past work (Kelemen et al., 2012). Before and after testing, we will perform memory checks to ensure that participants remember who made what tool, and what the tools are for.  
 Participants will be shown a goal for which a tool is needed (e.g., pushing a button inside a box that is accessible only through a small hole; see Figure 1). The goal apparatus will be identical across conditions, except that one apparatus will have a modification that limits the range of forms a successful tool could have. For example, instead of a tool simply having to fit through a larger round hole to reach the bell, the tool must fit through a smaller star-shaped hole. Thus in the functional constraint condition, the star-shape of the rod is a functionally necessary feature, as the other rods would not fit through the star-shaped hole. In the contrasting no functional constraint condition, all rods would fit through the round hole equally easily, so this shape choice is not functionally necessary. In the orthogonal availability constraint manipulation, all available rods will be either (a) of the same shape: the star shape (availability constraint condition); or (b) of different shapes, all of which fit through the round hole (no availability constraint).

Together, the functional constraint conditions and availability constraint conditions give a 2x2 design, manipulating the presence or absence of alternative explanations for similar designs in two separate ways. In this paradigm, we can thus test in two orthogonal ways whether adults’ and children’s reasoning is explanation-based vs. based on perceptual similarity, testing the formal model characterized in Aim 3.1.

*Procedure:* On each trial, children (and adults) will face a puzzle-box, and be asked to build a tool to solve the puzzle (e.g. a button inside a transparent cube, with only small hole to reach it). They will be offered pieces to build with, always starting with the same first piece (e.g. the handle) and choosing which second piece to attach to it to create a tool that will solve the puzzle (one of a set of rod pieces, Fig 1). A second character will be present in the room (for children, a puppet), who has the same set of options as the participant, and also builds something to solve the puzzle. The child will first be allowed to build their tool by selecting from the options, and to continue trying until they are able to solve the puzzle-box (by pushing the button). The puppet character will also build a tool, and always build the same tool as the child, making the same choice of rod. At test, the experimenter will say: “Now I’m going to show you what [the puppet] made,” and bring out the puppet’s creation alongside the participants’. In all conditions, this tool will be identical to the first tool; thus, the test stimuli will be perceptually identical across all Functional Constraint conditions and all Availability Constraint conditions.

We will then ask a forced-choice experimental question: Do you think [the puppet] copied you, or made that on his own? We will also ask children to explain their answers. To increase children’s motivation to deeply consider their answer, and help children identify copying only when they are confident it must have occurred, we can also use a more interactive dependent measure, having children choose whether to give the puppet a less desirable prize if they copied (e.g. a dirty rag versus a cookie, as previously used in Srinivasan & Snedeker, 2011). We will follow this with two memory check questions, to ensure that children remember who made what tool, and what the tools are for.

*Analysis and predictions*: If children of a given age are using a simple strategy of using perceptual similarity to judge likelihood of copying, then a) they should say that copying is equally likely regardless of the presence or absence of a Functional Constraint; b) they should say that copying is equally likely regardless of the presence or absence of an Availability Constraint; c) they should say that copying is less likely when the two tools are perceptually different than when they are perceptually similar (see Extensions below). In addition, they should appeal to perceptual similarity in their verbal explanations. If children are using richer explanation-based reasoning as instantiated in our Bayesian model, then per Aim 1, a) they should say that copying is more likely in the absence of a Functional Constraint than in the presence of such a constraint; b) they should say that copying is more likely in the absence of an Availability Constraint than in the presence of such a constraint.

*Pilot data:* We have tested a pilot version of this task with adults and children to ensure that this task is feasible. In this pilot version, the procedure and logic were similar but involved the creations of two other people, rather than the participant and one other person. Adults’ data were as predicted by our explanation-based reasoning model: When the shapes of the tools were unconstrained, two persons’ building the same tool was seen as good evidence of copying/ social transmission. When the shapes of the tools were functionally constrained (e.g. by the shape of the hole into the box), this similarity was ‘explained away’, and adults were significantly less likely to think the tool’s design had been copied/ socially transmitted (16% constrained vs. 53% unconstrained; *p*<0.01). In children (N=33, ages 4-7), our piloting focused on validating the task as a measure, and showing that children are capable of answering questions about copying, working together, and social transmission. We successfully validated this, and found preliminary support for possible developmental change in the extent of explanation-based reasoning: At the youngest ages, children seemed to reason largely based on perceptual similarity, whereas older children showed signs of explanation-based reasoning. Thus, this pilot data suggest that adults reasoning is likely rich and structured explanation-based reasoning; and that this reasoning may develop over the course of the ages we propose to test.

Based on this pilot data, we performed a power analysis on our main measure, estimating the rate of copying and the extent to which this would be affected by constrained vs. unconstrained conditions. As explained in Aim 1 (3.2), the model predicts large differences in the estimated rate of copying based on this manipulation, in line with the adult data (e.g., 50% vs 10% in the trial explained in 3.2, which mirrors the current experiment’s pilot data). Based on this estimated effect size and the planned across-participant conditions, we conducted a power analysis which suggested 17 participants per cell were required for 80% power (with alpha=0.05) to detect this predicted effect; 100 children per age gives us 25 per cell.

## 4.2 Extensions

In this Aim, we propose that the test stimuli will always be equally perceptually similar -- the puppet will always exactly copy the children’s tool. This case is particularly informative about the extent to which children use explanation-based reasoning, because the explanation-based reasoning account predicts “explaining away” in some but not all conditions (leading to a drop in how likely copying is perceived to be), whereas the perceptual similarity account does not predict this pattern. However, it is also important to generalize the results and the model predictions to other cases, which we can feasibly do by extending the current paradigm using similar methods. For instance, we can test inferences about stimuli that are perceptually different to various extents -- e.g., when the puppet makes one or more different design choices from the child. We can also vary contextual factors, such as visual access (whether the puppet can or cannot see the child’s design). If children are truly reasoning from the extent of perceptual similarity, the number of different perceptual features should systematically reduce their judgement regarding social transmission, and contextual factors such as visual access should not. If children are instead making a more complex inference, which includes some judgement of the prior likelihood of copying, then both contextual factors and extent of perceptual similarity should play a role.

# 5. Aim 3: Reasoning about the social origins of artifacts in a realistic artifact-creation task

The tool selection task in Aim 2 involves a very straightforward decision - a single choice of which rod to attach, where in the *constrained* scenario only one of the rods can achieve the goal. In Aim 3, we propose a richer train track building task, which allows us to tease apart our two models’ predictions in novel ways. The structure of this task is as follows (see Figure 2): Imagine you see a train track built by person 1, track *t*, and then you are shown a new train track, *t2*, built by person 2. You wish to infer whether person 2 copied the track’s design from person 1, or independently created it.

Our two models - *perceptual heuristics* vs. *explanation-based reasoning* - make different behavioral predictions that we will test experimentally. In Aim 2, we manipulated the functional constraint by changing the puzzle box, such that for one condition, some tools worked and others did not work to achieve the goal. In Aim 3, we test a different question, also about functional constraints, by testing the role of children’s efficiency expectations in constraining the structure of artifacts. In particular, we will manipulate the strength of people’s expectation for how efficient the person building the track was trying to be. On *strong efficiency expectation* trials, participants will be told that the people who created the track had to build a track ‘to quickly get from house A to house B’. On *weak efficiency expectation* trials, participants will be told that the people who created the track had to build a track ‘to have fun, and play around with the track-building game. The track just had to connect house A and house B.’ We predict that if children are using explanation-based reasoning, they will take into account efficiency when considering functional constraints. If so, then on strong efficiency expectation trials, building an identical but highly efficient track should *not* be seen as strong evidence of copying - since there is an alternative explanation for how both individuals independently came up with this design, due to the functional constraint of the need for efficiency. On weak efficiency expectation trials, building the same highly efficient track will be seen as stronger evidence of copying than in the other condition, while in both conditions building the same *low-efficiency* track will be seen as strong evidence of copying. This pattern of result would provide evidence that (a) children are reasoning using more than just perceptual similarity; (b) efficiency (a type of functional constraint) can be taken into account when reasoning about artifact design and social history.

Secondly, our Bayesian implementation of the explanation-based model predicts that the availability constraint will play a significant role above and beyond the mere perceptual similarity of the tracks. To manipulate availability, in Aim 2, we changed how many options of rods were available to participants to select. Here, we test a different way of manipulating the availability constraint -- rather than manipulate how many pieces participants have to build with (as in Aim 2), we propose to manipulate the presence or absence of a barrier, that prevents a large number of possible tracks from being built (see Figure 3; brick wall). This brick wall cannot have tracks pass through it, thus severely limiting the number of potential tracks that could be built. This provides a crucial way to tease apart the predictions of our two models: If participants are using only perceptual similarity, this barrier should make no difference for their judgements of whether the design was copied. If participants are making a more complex explanation-based inference, then on *barrier* trials (high availability constraint), it should not be seen as coincidental if two people make the same long track -- so long as that track is the best option from those available. This similarity should be explained away as not due to copying, but instead to a constraint on available track options. In contrast, on *no-barrier* trials (no availability constraint), two people creating the very same long track should be judged to have copied, as in this case other better design options were available.

Thus, as in Aim 2, we will have a 2x2 design manipulating the functional constraint and availability bias. However, in Aim 3, we manipulate these in qualitatively distinct ways, providing an independent window into the use of functional constraints (strength of the efficiency expectation), and availability constraints (presence or absence of a barrier).

## 5.1 Train track building task

*Participants:* Adults and children. As in the tool selection task, we plan to test children at age 4, 6 and 8 (100 participants at each age), as well as adults (18+ years), to examine developmental change.

*Method* – This set of experiments will involve reasoning about social origins of complex artifacts built by others to achieve a particular purpose. The basic structure of this task is that two people have built a train track to get from house A to house B on a grid -- and they end up creating the same, similar, or different tracks; that are either highly efficient (get quickly from house A to house B), or not very efficient (have twists and turns instead of going directly from A to B). The main dependent measure is: when do participants judge that the design was copied?

As described above, we systematically manipulate the functional constraints on the task by manipulating people’s efficiency expectations. Thus, on half of the trials, *strong efficiency expectation* trials, participants will be told that the people who created the track had to build a track ‘to quickly get from house A to house B’. On *weak efficiency expectation* trials, participants will be told that the people who created the track had to build a track ‘to have fun, and play around with the track-building game. The track just had to connect house A and house B.’ Orthogonally to this manipulation, we will also manipulate the available constraint. Thus, on half of the trials, a barrier will be present (*barrier* trials), and on half of the trials, no barrier will be present (*no-barrier* trials). This gives us a 2x2 design.

*Procedure:* Every adult participant will participate in each condition, including multiple trials of each. Stimuli will be presented on a computer screen, with each trial presenting a pair of train tracks (created by two different people), and asking participants to judge whether they were copied or independently created. The experimental design will be blocked, with blocks of trials for each condition in counterbalanced order across participants, and the order of trials randomized within a block. Blocks will include a 2x2 design manipulating the presence or absence of (a) The availability constraint (barrier/ no barrier); (b) The strength of the functional constraint (strong efficiency expectation; weak efficiency expectation). We will test a variety of track designs, particularly focusing on track designs deemed particularly informative by the model in teasing apart the predictions of our two accounts. For example (Fig 3), the track that goes directly around the barrier provides one informative test case: If our Bayesian explanation-based reasoning model accounts for people’s reasoning, then two people creating this same track should be seen as strong evidence of copying in the absence of the barrier, but not when it is present. If participants use only the extent of perceptual similarity, then this track should be equally strong evidence of copying in both conditions.

*Procedure for testing children:* Due to constraints on children’s memory and executive function, children will participate only in a single pair of conditions: either the availability constraint manipulation (barrier/ no barrier), or the functional constraint manipulation (strong efficiency expectation/ weak efficiency expectation). In addition, we will present the setup for the track building in a more concrete manner, using videos involving two puppets that create the two tracks (as used in previous work on comprehension of copying in early childhood: Olson & Shaw 2011). The basic sequence of events will be identical for all videos, with variations for each condition.

In the “strong efficiency expectation” condition, an adult will say to the puppets: “can you build a track to get Thomas the train home as fast as he can?”. In the “weak efficiency expectation” condition, an adult will say to the puppets: “Here are some fun train track toys. You can play around with the train tracks, and make some fun, cool shapes!” In the availability constraint condition, the adult will also explain the constraint, saying “there’s a brick wall here -- the track can’t go through it!” In the no availability constraint condition, the adult will provide a similar explanation of matched length, e.g. “here’s the game board -- you can put the tracks on it!” In all conditions, the video will then continue in an identical manner. Puppet A will ask, ‘How should I build my train track?’, and Puppet B will say, ‘I can’t decide what to build.’ After a pause Puppet A will state, ‘Oh, I know what I’ll build’, and proceed to begin building. After a moment, Puppet B then will say: ‘Oh, I know what I’ll build’. After a pause, Puppet A will lift his train track up and state to the camera, ‘See what I built?’, and then Puppet B will lift his track and state, ‘See what I built?’

*Analysis and predictions*: If children are using a simple strategy of using perceptual similarity to judge likelihood of copying, then a) they should say that copying is equally likely regardless of the presence or absence of a Functional Constraint; b) they should say that copying is equally likely regardless of the presence or absence of an Availability Constraint; c) they should say that copying is less likely when the two tracks are perceptually different than when they are perceptually similar. If children are using richer explanation-based reasoning, as instantiated in our Bayesian model, to reason about the underlying generative process of artifact creation, then per Aim 1, a) they should say that copying is more likely in the absence of a Functional Constraint than in the presence of such a constraint; b) they should say that copying is more likely in the absence of an Availability Constraint than in the presence of such a constraint; and c) they should still say that copying is less likely when the two tools are perceptually different than when they are perceptually similar (see Extensions below).

*Pilot data:* We have tested a pilot version of this task with adults to ensure the feasibility of the design (N=6). Adults’ data were as predicted by our explanation-based reasoning model: For example, sets of long and inefficient tracks like in Figure 2 were highly likely to be seen as copied (median 71% of participants across different pairs of tracks) from each other; whereas the exact same tracks, but with a barrier to “explain away” some aspect of the similarity according to an availability constraint were seen as much less likely to be copied from each other (median 28% of participants across different pairs of tracks). In addition, agreement among participants was high across many pairs of tracks, suggesting that we once again have sufficient power to detect relatively subtle differences in the likelihood of social transmission.

# 6. Collaboration Plan

The two PI’s have complementary expertise that is ideally suited for this collaboration. Dr. Schachner is an expert on the relevant aspects of cognitive development and social cognition, having published on topics ranging from how we understand actions and the role of efficiency expectations in this reasoning (Schachner & Carey, 2013) to the role of function in children’s explanations of natural phenomena (Schachner, Zhu, Li & Kelemen, 2017) to the role of infant-direct speech in social learning (Schachner & Hannon, 2011). She has expertise in working with children of all ages, ranging from infancy (e.g., Schachner & Hannon, 2011) to preschoolers (Mehr, Schachner, Katz, Spelke, 2013) to school-aged children (Schachner et al. 2017). In addition, Dr. Schachner is deeply involved in the effort to improve the psychological sciences, including publishing on how best to improve the replicability of psychological science (e.g., Hartshorne & Schachner, 2012). Dr. Brady is an expert on computational modeling and Bayesian inference (e.g., Brady & Tenenbaum, 2013; Brady, Konkle & Alvarez, 2009; Brady & Alvarez, 2015). His lab is broadly interested in topics in learning (e.g., Brady & Oliva, 2008) and memory (e.g., Brady, Konkle, Alvarez & Oliva, 2008), including applying Bayesian inference to explain multiple factors in people’s decisions, as in the current proposal (e.g., Brady & Tenenbaum, 2013).

The PIs have collaborated successfully before, both on intellectual pursuits, resulting in a *Current Biology* paper on motor entrainment to music (Schachner, Brady et al. 2009), as well as on broader impacts (having taught many outreach courses for high school and middle school students together). They have lab spaces at UC San Diego in the same building, ideally suited for collaboration. The budget is designed to fund a graduate student who will work jointly with the PIs. In addition, Dr. Gail Heyman, a leader in the study of social cognition in preschool children, is also in same building of the department of Psychology at UC San Diego, with the PIs. She has agreed to provide her expertise and support, both in advising the graduate student and providing feedback on the research (see Letter of Collaboration, attached).

# 7. Project Schedule and Milestones

The following table presents a set of project milestones that provide a framework for *evaluating* the success of the proposed research and broader impacts:

|  |  |  |
| --- | --- | --- |
|  | **Intellectual Merit goal** | **Broader Impacts goal** |
| Year 1 | Collect adult data on Aim 2 and Aim 3 experiments, develop and expand the model to its full breadth (Aim 1) | Training graduate student in computational modeling; presentations at Cognitive Development Society (CDS); outreach to public via talks at local science events and community colleges. |
| Year 2 | Run children (Aim 2); write up modeling/adult manuscript. | Training graduate student in modeling and preschool data collection; presentations at CDS; continued outreach. |
| Year 3 | Finish children studies (Aim 3). Manuscript preparation for Aim 2 and Aim 3 studies. | Training graduate student in manuscript writing and presentation; presentations at CDS; continued outreach. |

# 8. Broader Impacts

(1) The proposed research involves training graduate students on all aspects of research, including experimental and modeling techniques as well as data analysis and manuscript preparation. They will be trained to design and program experiments, design and build computational models, and analyze behavioral data from adults and children. They will thus be qualified to make future contributions to the field of computational cognition. In addition, they will learn to communicate with the public about their research, through recruitment efforts and outreach.

(2) Involvement of women and members of underrepresented groups. The PIs place particular emphasis on involving women, students from underrepresented groups and first-generation college students in research (see Biosketches). The proposed research will lead to increased involvement of these groups in research in STEM. Furthermore, our study population – including adults and children -- includes a wide range of families from differing socioeconomic backgrounds, including members of a large Hispanic community, a group we particularly emphasize in recruitment.

(3) Research dissemination and benefits to society. In addition to presentations by both the graduate students and PIs at scientific conferences, both PIs are also involved in outreach efforts, for example, giving talks at local community colleges and other public outlets for research, and interacting with families at preschools and museums (see Biosketches). We will continue and expand these efforts at outreach to disseminate findings about cognitive development and the current findings to the public.

(4) The proposed research will advance the understanding of the role of objects in children’s social reasoning. From early preschool age, children face the challenge of interacting with multiple new people, understanding existing social ties, and choosing social partners. Social cues from artifacts may serve as implicit social glue, providing a foundation for smooth social interaction by identifying others with similar interests and social history. Understanding this reasoning process is thus a clear next step in characterizing social cognitive development.

# 9. Results from Prior NSF-funded Research:

Timothy Brady is PI on multiple NSF grants, the most relevant of which is an NSF CAREER Award (BCS-1653457, "CAREER: Spatial Ensemble Structure in Visual Working Memory” 2017-2022; $585,440). No papers have yet been published under this grant, which commenced less than 6 months ago and involves understanding the capacity of visual working memory for objects and global ensemble representations, including some Bayesian modeling components; This grant also includes significant broader impacts, including the development of tools for researchers (Mechanical Turk tutorials) and science outreach (summer program for first-generation college students sponsored by the PI).

1. These are computationally tractable to normalize over; considering all tracks with up to 7 straight pieces and 7 turns gives only 7795 possible tracks. [↑](#footnote-ref-1)
2. With the pictured barrier, the number of possible tracks drops from 7795 to 664. [↑](#footnote-ref-2)