Children's unexpected inferences across knowledge types

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Abstract

Developmental psychologists have often turned to children to clarify understanding of functional and mechanistic cognition. Here, we investigate children's epistemic inferences of function – what a thing is for – and mechanism – how a thing works. Children, like adults, believe a mechanism-knower knows more than a function-knower (Study 1). Yet, unlike adults, children do not expect that a mechanism-knower is also more likely to know function than a function-knower is to know mechanism (Study 2). Children's experience of learning function and mechanism of complex systems sheds light on this asymmetry; Children who are taught just mechanism can infer the complementary function, but, interestingly, children who are taught just function can likewise infer the complementary mechanism (Study 3). This paper considers the nature of children's epistemic intuitions and whether those beliefs are reflective of children's learning experience.

Keywords: development; knowledge; function; mechanism; epistemic inferences

Introduction

Who knows more about a lightbulb: someone who knows what the lightbulb is for or someone who knows how it works? Which of these two people likely actually already knows both what a light bulb is for and how it works? History provides one suggestion: fire, candles, and oil lamps were used for millennia before anyone discovered how to illuminate filaments using electricity. Developmental trajectories might too provide an answer; children's judgments and learning outcomes have often been used to consider the nature of supposedly nuanced cognitive artifacts, such as the relation between function and mechanism. Here, we consider whether children have established intuitions regarding the nature of functional knowledge – understanding of what a thing's purpose is or what it is for – and mechanistic knowledge – knowledge of how a thing's component parts causally interact to make it work. Further, we consider whether these intuitions align with adult epistemic inferences and whether these intuitions might be a consequence of children's experiences encountering complex systems.

Educators have turned toward mechanistic explanations as a means of deepening student understanding beyond surface-level details (NGSS, 2013), but the cognitive and pedagogical relation of function and mechanism is complex. Philosophers of science often debate over the degree of interrelatedness of function and mechanism (Bechtel, 2011; Craver, 2013; Craver, 2015; Povich & Craver, 2017). Psychologists have found that adults – even scientific experts – endorse functional explanations when they should principally accept only mechanistic explanations (Kelemen, 1999a; Kelemen 1999b). Adults are often incorrect in their intuitions of whether and how to teach about complex mechanisms; lay adults believe complex functional and mechanistic explanations are too complicated for children, despite the ability of even young children to learn about a mechanism as complex as a combustion engine (Chuey, et al., 2021). Similarly, recent work has demonstrated that adults strongly prefer that explanations provide functional information before mechanistic information despite there being no evidence that doing so is beneficial to learners (McCarthy & Keil, 2023; McCarthy et al., 2024).

Prior work has used developmental research to shed light on the nuance of functional and mechanistic cognition. For example, when considered in conjunction with research on participants suffering from neurodegenerative diseases and experts' inappropriate endorsement of functional explanations (Lombrozo et al., 2007; Kelemen et al., 2013), work on children's endorsement of functional explanations demonstrates how unscientific beliefs may be suppressed, rather than replaced (Shtulman & Valcarcel, 2012). Further, much work has determined that, despite theories of the complex relation between function and mechanism, even children can instinctually differentiate the two information types (Kelemen, 1999b). For example, children intuitively ask functional questions of whole artifacts, but not of whole animals (Grief et al., 2006). Only one study to our knowledge, however, has investigated children's epistemic beliefs by juxtaposing functional and mechanistic knowledge. When trying to fix an object – but not when selling that object – children believe mechanistic knowledge is more valuable than functional knowledge (Lockhart, et. al, 2019, Study 4).

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Current Studies

Here we consider 6- to 9-year-old children as they are at an age where they can successfully learn and retain knowledge about complex mechanisms (Chuey et al., 2021) and even make nuanced epistemic inferences such as when mechanistic knowledge appropriately generalizes (i.e., in superordinate categories; Lockhart et al., 2019). By complementing adult-centric intuition research with developmental methods, the current studies determine whether children have established intuitions of functional and mechanistic knowledge, whether those intuitions align with those of adults, and whether children's or adults' pedagogical and epistemic intuitions better capture the nature of children's learning of complex entities.

Study 1 asks both children and adults to decide which person they believe knows more about an object, someone who knows the object's function or someone who knows the object's mechanism. Study 2 probes for whether adults and children believe one of these knowledge types is cognitively before the other by asking participants to indicate whether a function-knower or a mechanism-knower is more likely to have knowledge of both what a thing is for and how it works. Study 3 teaches children either functional information or mechanistic information to determine whether children can infer one knowledge type from another without it being explicitly taught to them. To consider the breadth of these findings, each study considers both artifacts (e.g., laser welder) and biological parts (e.g., swim bladder of a fish).

Study 1

While prior work has determined that children can accurately differentiate an expert from a non-expert after being taught about a complex artificial system (Chuey et al., 2021) and other work has demonstrated nuanced intuitions of when mechanistic expertise is more valuable than functional knowledge (i.e., in the context of fixing; Lockhart et al., 2019), we nevertheless have limited insight into children's intuitions of how functional and mechanistic knowledge compare. Here, we ask children (6- & 7-year-olds, 8- & 9-year-olds) and adults to decide which of two characters they believe knows more about an object or animal's body part: a person who knows "what the thing is for, like what job it does and what it's used for" (function-knower) or a person who knows "how the thing works, like how the parts inside move together to make it work" (mechanism-knower). Though we do not expect domain effects, this study parallels prior work in considering whether these intuitions apply across artifacts and biological parts. We expect that, across both domains, both adults and children will indicate that mechanism-knowers have more knowledge about the stimuli than do their function-knowing counterparts. All studies in this paper were pre-registered with AsPredicted.org and pre-registrations, as well as code, data, and supplemental materials are available on our OSF page (DOI 10.17605/OSF.IO/V32X6).

Methods

Participants in the developmental age-groups participated via live videochat with a researcher, provided assent prior to participation, and were compensated with a $5 Amazon giftcode. No children failed any of the 3 attention checks, nor were any excluded for lack of attentiveness or technical difficulties according to pre-registered criteria. Adult participants who completed the survey, independent of whether they passed attention checks, were compensated $0.75; median survey time was 3.2 minutes; therefore, participants were compensated at an approximate rate of $14.06 per hour.

All power analyses in this paper were conducted using pwr package version 1.3.1 (based on Cohen, 1988). For Study 1's general linear models, an a priori power analyses determined that 90 participants would be sufficient to find a significant ($\alpha = .05$) between-subjects effect with a medium effect size ($f2 = .15$) and a medium power ($1 - \beta = .8$).

Study 1 consisted of 90 participants equally divided amongst 3 age groups: 6- & 7-year-olds ($M_{Age} = 7.1$ years; 15 female, 15 male; 0 excluded and replaced), 8- & 9-year-olds ($M_{Age} = 8.8$ years; 14 female, 16 male; 0 excluded and replaced), and adults ($M_{Age} = 35.3$ years; 16 female, 13 male, 1 non-binary; 1 excluded and replaced).

Participants in 3 age groups (6- & 7-year-olds, 8- & 9-year-olds, Adults) were randomly assigned to one of two domain conditions (artifacts, biology) where they responded to a total of 3 attention check questions and 3 outcome measures.

Participants were first introduced to a set of twins and asked two attention check questions: "Which twin has black hair" and "Which twin has pink hair". Per pre-registered criteria, participants who failed to correctly respond to either question would be excluded and replaced. Next, participants were serially introduced to 3 more sets of twins. Each set of twins was accompanied by an image of a single stimulus item with respective to Domain condition and assigned counterbalance. Participants were asked to indicate which twin they believed knew more about the stimulus item:

> "Blue" knows what this thing is for. For example, he knows what this thing's job is and what it is used for.
> "Green" knows how this thing works. For example, he knows how the parts inside move together to make the thing work.
> Who do you think knows more about this thing?

A final set of twins was then presented. Participants were asked to decide which of these twins knows more about the biomechanical item: the twin that says, "I've seen this thing before and have read a few different books about it" or the twin that says, "I have never seen this thing before and don't know anything about it."

Results and Discussion

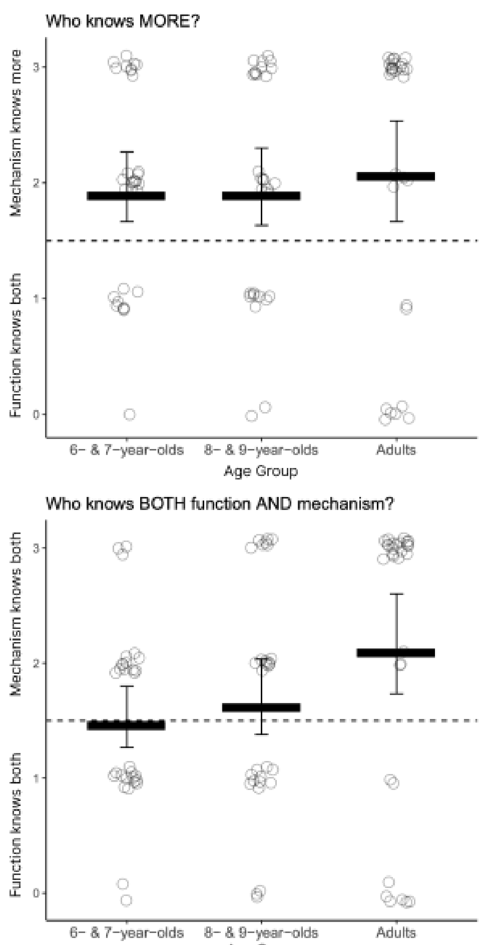
Results are shown in Figure 1. To assess whether participants' judgments of knowledge differed from chance, 95% bootstrap confidence interval testing was conducted.

Then, generalized linear regressions were used to determine whether judgments varied as a function of Age Group (factor: 3 levels) or Domain (factor: 2 levels). For all regressions in this paper family was specified as Gaussian and contrast coding was used to compare condition to the grand mean of the data. Responses indicating that mechanism-knowers knew more were coded as a 1 and responses indicating that function-knowers knew more were coded as a 0.

Pre-registered 95% bootstrap confidence interval testing determined that 6- & 7-year-olds (95% CI [1.667, 2.267]), 8- & 9-year-olds (95% CI [1.633, 2.300]), and Adults (95% CI [1.733, 2.567]) were all significantly above chance (1.5); Participants in all age groups considered mechanism-knowers as knowing more than functional-knowers.

A generalized linear regression revealed no effect of Domain (β = -0.114; p = .288). There was also no effect of Age Group: 6- & 7-year-olds did not differ from 8- & 9-year-olds (β = -0.061; p = .686) or Adults (β = 0.133; p = .379), nor did 8- & 9-year-olds differ from Adults (β = -0.072; p = .632). Further, there was no interaction between Domain and Age Group: (β = 0.014; p = .928 for younger children vs. older children; β = 0.028; p = .063 for younger children vs. adults; β = -0.297; p = .052 for older children vs. adults).

Study 1 finds that children and adults agree in their intuitions that knowing mechanism indicates greater overall understanding of an entity than does knowing function. Results were consistent both across age groups and across domains, suggesting a robust and developmentally stable mental model of functional and mechanistic knowledge types. Study 1 therefore establishes the perceived relative magnitudes of function and magnitudes as well as providing evidence that these nuanced intuitions are relatively early developing.



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Study 2

While Study 1 provides insight into the believed magnitudes of functional and mechanistic knowledge, Study 2 sets out to consider the relation between these knowledge types.

Adults seem to believe that functional knowledge necessarily precedes corresponding mechanistic knowledge (McCarthy & Keil, 2023), but it remains unclear whether such intuitions are the result of an expectation of a foundation-type role of function. That is, adults may indicate that function should come before mechanism in an explanation because they believe that understanding function is foundational to mechanistic knowledge. However, this preference might also be explained by other presumed features of function or mechanism. Perhaps mechanistic knowledge is considered relatively more difficult to learn and understand than function, or function is more possible to learn independent of mechanism compared to learning mechanism without a corresponding function.

Here, we determine whether children and adults have as strong intuitions regarding the cognitive structure of functional and mechanistic knowledge as they do regarding their magnitude (Study 1) by asking participants to consider whether one knowledge-type implies the other. Study 2 uses identical methods to Study 1 with only the below noted exceptions to consider who people believe is more likely to know *both* function and mechanism: someone who knows function or someone who knows mechanism. A large effect in either direction would suggest that one knowledge type is primary to the other, either because it is foundational to the second knowledge type or because, for example, it is easier to attain. Results at chance would suggest either that people perceive no strong relation between the two information types, or that people believe functional knowledge to just as strongly imply mechanistic knowledge as mechanistic knowledge implies functional knowledge.

Methods

Participants Study 2 methods, including recruitment and exclusion criteria for participants, were identical to Study 1 except for the following exceptions. As in Study 1, a power analysis determined that 90 participants would be sufficient across 3 age groups. So far, data has been collected for 89 participants: 6- & 7-year-olds (M_{Age} = 7.1 years; 14 female, 16 male; 1 excluded and replaced for failing final attention check), 8- & 9-year-olds (M_{Age} = 9.1 years; 12 female, 17 male; no exclusions), and adults (M_{Age} = 39.5 years; 16 female, 13 male, 1 non-binary; no exclusions). Adult participants who completed the survey, independent of whether they passed attention checks, were compensated $0.85; median survey time was 3.2 minutes; therefore, participants were compensated at an approximate rate of $15.93 per hour.

Study 2 deviated from Study 1 only in that participants made judgments in response to a different question:

> "Blue" knows what this thing is for. For example, he knows what this thing's job is and what it is used for.
>
> "Green" knows how this thing works. For example, he knows how the parts inside move together to make the thing work.
>
> But one of these twins actually knows ***both*** what this thing is for ***and*** how this thing works. Which twin do you think actually knows ***both***?

Results and Discussion

Results are shown in Figure 1. 95% bootstrap confidence interval testing and generalized linear models were respectively used to determine whether participants' responses differed from chance and whether they varied as a function of Domain or Age Group. Responses indicating that mechanism-knowers knew both were coded as a 1 and responses indicating that function-knowers knew more were coded as a 0.

Pre-registered 95% bootstrap confidence interval testing determined that only Adults (95% CI [1.767, 2.633]) were all significantly above chance (1.5); 6- & 7-year-olds (95% CI [1.267, 1.800]) and 8- & 9-year-olds (95% CI [1.345, 2.034]) did not vary from chance in their judgements, while Adults indicated mechanism-knowers were more likely to know *both* function and mechanism than were function-knowers.

The model revealed no effect of Domain ($\beta = 0.197$; $p = .070$), nor of Age Group: 6- & 7-year-olds did not differ from 8- & 9-year-olds ($\beta = -0.276$; $p = .071$), nor did 8- & 9-year-olds differ from Adults ($\beta = -0.098$; $p = .523$). However, 6- & 7-year-olds did vary significantly from Adults ($\beta = 0.374$; $p = .015$) where adults ($M_{Adults} = 2.167$) more strongly believed the mechanism-knower knows both than did children in the youngest age group, who were at chance ($M_{6\text{- \& 7-year-olds}} = 1.533$). Further, there was no interaction between Domain and Age Group: ($\beta = -0.141$; $p = .357$ for younger children vs. older children; $\beta = -0.141$; $p = .357$ for younger children vs. adults; $\beta = 0.170$; $p = .273$ for older children vs. adults).

Study 2 finds that adults believe that someone who knows how an artifact or biological part works is more likely to also knows what that thing is for than a function-knower is to also know mechanism. That is, adults believe in an asymmetrical relation between functional and mechanistic knowledge: mechanistic knowledge implies functional understanding, but functional knowledge does not imply mechanistic understanding. Children, on the other hand, do not demonstrate this preference. While they indicated in Study 1 that mechanism-knowers have greater knowledge than do function-knowers, children do not ascribe to the belief that mechanistic knowledge implies functional knowledge.

A deflationary account would suggest that children's non-preference indicates that they simply did not understand the task. However, significant differences in Study 1 and even more complex inferences regarding the ability of mechanistic knowledge to generalize to superordinate categories using a very similar paradigm (Chuey et al., 2020) provides evidence that children can make nuanced epistemic inferences within this paradigm.

Taken at face value, Study 2's findings demonstrate a difference in adults' and children's intuitions of cognitive structure.

Study 3

Study 1 demonstrates that both children and adults believe mechanism indicates greater knowledge than does functional understanding. Study 2, however, captures a developmental divergence: adults, but not children, believe that mechanistic knowledge implies corresponding functional knowledge. Study 3 investigates whether this difference in epistemic intuition might be an artifact of experience. Perhaps it is the case that, for child-directed explanations, mechanistic information can be extracted from functional explanations just as easily as functional information is drawn from mechanistic explanations. Study 3 therefore will present children with either a functional explanation or a mechanistic explanation before testing their subsequent knowledge of both function and mechanism. Adults' intuitions suggest that participants in the Mechanism lesson condition should be able to infer function, but participants in the Function lesson condition will not be successful in inferring mechanism. Specifically, Mechanism condition participants should perform above chance on both measures of mechanism – which they will be explicitly taught – and measures of function – which will have to be inferred – while participants in the Function condition should only perform above chance on measures of function. Children's intuitions, on the other hand, predict that learners in either condition will be just as successful in inferring the opposite information type. If children are accurate and lessons provide positive learning gains as expected by researchers, then Mechanism condition and Function condition participants – but not $\text{Control}_{\text{No Lesson}}$ participants – will perform above chance on both function and mechanism, and Function condition participants will likewise perform above chance on both function and mechanism measures.

Methods

Participants in Study 3 participated via video chat study and were compensated with a $5 Amazon gift code.

Study 3 analyses consider 125 participants across two age-groups: 6- & 7-year-olds ($M_{Age} = 6.9$ years; 32 female, 33 male; 3 exclusions) and 8- & 9-year-olds ($M_{Age} = 8.9$ years; 27 female, 33 male; 2 exclusions). 5 participants were excluded and replaced for either being judged by the experimenter to by inattentive (4) or for failing to identify which character was an expert (1).[1]

In this 2 (Age group: 6- & 7-year-olds, 8- & 9-year-olds) x 2 (Domain: Artifact, Biology) x 3 (Lesson: Control$_{\text{No Lesson}}$, Function-first, Mechanism-first) between-subjects design randomly assigned participants to consider 1 of 4 potential stimulus items that was either a biological part (fish's swim bladder, lightning bug's light organ), or an artifact (e.g., laser welder, power steering system). All participants were asked 6 questions probing content knowledge: 3 questions about function and 3 questions about mechanism.

After being introduced to the task, participants in the lesson conditions (Function, Mechanism) were read explanations accompanied by animated visuals, while participants in the Control$_{\text{No Lesson}}$ condition did not receive a lesson. Next, participants were introduced to the expert-detection paradigm and asked as an attention check to indicate which of two people was the expert, someone who has seen the object before and read several books about it, or someone who has never seen the thing before. Participants who failed to correctly identify the expert here were excluded from analyses. Next, participants were asked a total of 6 dependent measures questions. Control participants received questions in a counterbalanced order, alternating between questions of function and mechanism. To prevent dependent measures from incidentally providing information from the opposing information type prior to aligned measures being complete, questions for Function lesson and Mechanism lesson presented one of 4 counterbalanced orders first aligned questions, then opposite information-type questions. For example, a participant in the Function-only condition would answer all 3 function questions (e.g., for children, whether "This body part [Swim Bladder] makes sure the fish can stay

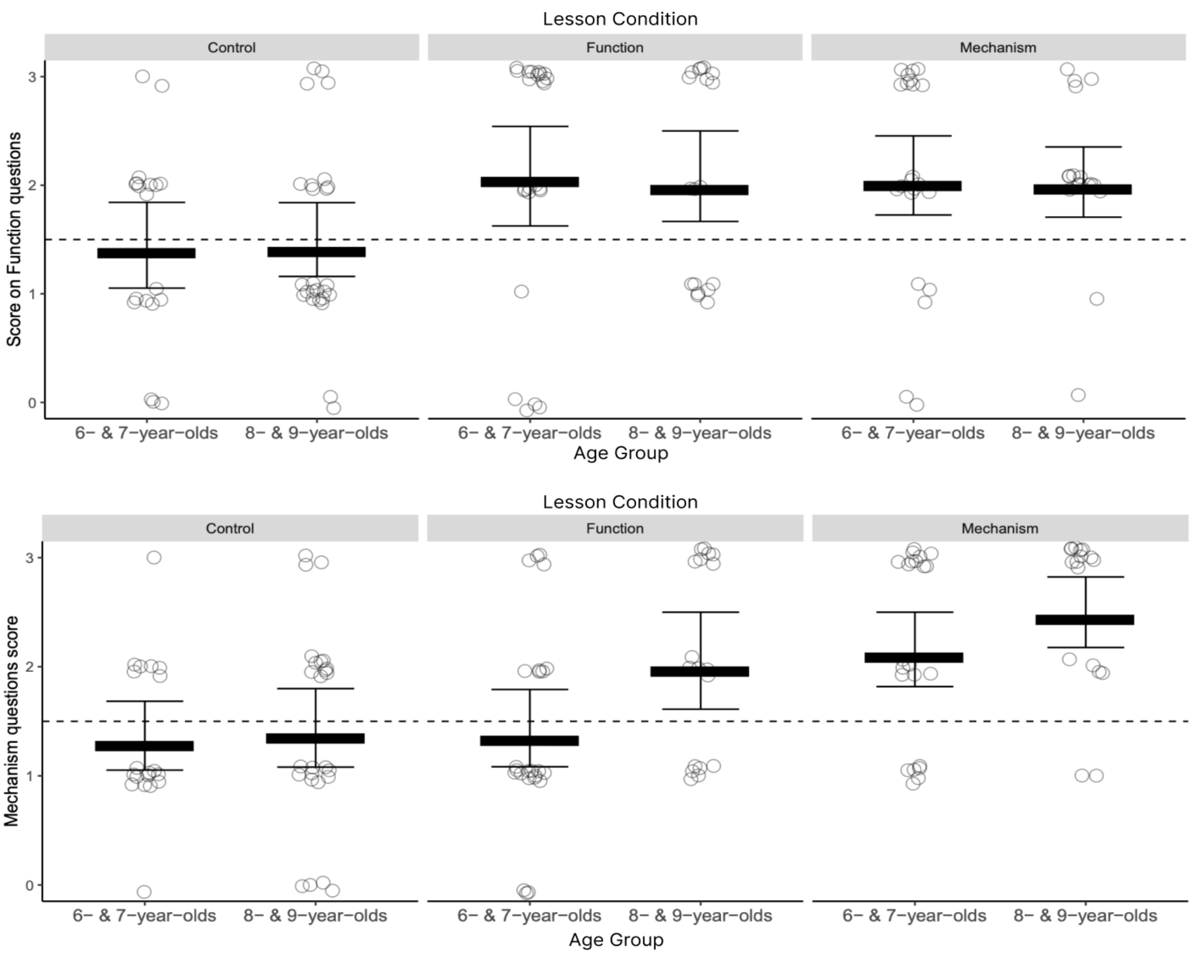

Figure 2: Results of Study 3. Answers are presented by lesson condition. Performance on answers to mechanism questions are in the top plot, and performance on answers to function questions in in the bottom plot. Question score refers to the number of correct answers. Error bars represent 95% bootstrapped confidence intervals.

[1] Study 3 presents the combined data of 2 yet unpublished studies. The control condition comes from a study with 3 lesson conditions: Control$_{\text{No Lesson}}$, Function-then-Mechanism lesson, and Mechanism-then-Function lesson, while the Function-only and Mechanism-only lesson conditions presented here are the only two that study design. Therefore, the number of participants required according to preliminary power analyses is pre-registered, but ultimately appears disjointed here. Despite unequal sample sizes, all data collected so far will be presented here to present the most complete picture possible.

still in the water more easily" or "[…] stay *warm* in the water more easily") before answering all 3 mechanism questions (e.g., for children, whether "When this body part gets bigger, it makes the fish go *deeper down*" or "[…] *higher up*").

Results and Discussion

Results are shown in Figure 2. To assess whether participants' performance differed from chance, 95% bootstrap confidence interval testing was conducted. Then, generalized linear regressions were used to determine whether performance varied as a function of Lesson (factor: 3 levels), Age group (factor: 2 levels), or Domain (factor: 2 levels). Independent regressions predicted the sum of function scores and sum of mechanism scores.

In the Control condition, neither 6- & 7-year-olds (function: 95% CI [1.105, 1.895]; mechanism: 95% CI [1.053, 1.632]) nor 8- & 9-year-olds (function: 95% CI [1.160, 1.800]; mechanism: 95% CI [1.080, 1.800]) differed from chance (1.5) in their performance on function questions or mechanism questions.

In the Function condition, 6- & 7-year-olds (95% CI [1.708, 2.583]) and 8- & 9-year-olds (95% CI [1.667, 2.500]) performed above chance on function questions. On mechanism questions, though, 8- & 9-year-olds (95% CI [1.667, 2.444]), but not 6- & 7-year-olds (95% CI [1.042, 1.792]) were above chance.

In the Mechanism condition, both 6- & 7-year-olds (function: 95% CI [1.727, 2.500]; mechanism: 95% CI [1.818, 2.545]) and 8- & 9-year-olds (function:95% CI [1.706, 2.412]; mechanism: 95% CI [2.235, 2.882]) performed better than chance on both function and mechanism learning measures.

The Function model revealed that the kind of lesson that participants received did not influence performance (β = -0.003, p = .995) or Age Group (β = .002, p = .993). Further, even when considering only participants who received a lesson and collapsing across Domain, neither Lesson condition (β = .008, p = .944) nor Age Group (β = 0.025, p = .816) predicts functional learning outcomes.

The Mechanism model revealed that while Age Group does not predict performance (β = 0.139, p = .548), the kind of lesson that participants received significantly influenced performance (β = -0.631, p = .001): Mechanism participants ($M_{Mechanism}$ = 2.333) did better on mechanism questions than did Function participants ($M_{Function}$ = 1.690). When considering only participants who received a lesson and collapsing across Domain, there continued to be an effect of Lesson condition on mechanism questions (β = -0.428, p < .001). There was also an effect of Age Group (β = -0.176, p = .023) where older children ($M_{8\text{- \& 9-year-olds}}$ = 1.933) did better than younger children ($M_{6\text{- \& 7-year-olds}}$ = 1.662).

Study 3 presents children either with functional information, mechanistic information, or no information at all before probing their understanding of the function and mechanism of a novel entity. Participants who received a lesson – either Functional or Mechanistic – performed at rates above chance on questions of function. However, performance on mechanism questions was moderated by lesson condition; children in the Mechanism condition performed satisfactorily on mechanism questions, but older children in the Function condition performed worse and younger children were not different from chance. That is, while participants who learned about Mechanism were able to infer corresponding functional information quite easily and performed just as well as Function learners, participants who learned about Function were not able to so easily infer mechanistic information. However, for older children, even these function-learners still performed above chance on mechanism questions.

General Discussion

Study 1 participants across age groups demonstrated a belief that mechanism-knowers know more about an entity than function-knowers do. In Study 2, children's intuitions diverge from those of adults in that they do not believe that mechanism-knowers are more likely to know function than function-knowers are to know mechanism. Study 3 considers whether this belief corresponds to children's experiences in learning about complex functions and mechanisms. Results of Study 3 found that for both developmental age groups, mechanistic lessons fostered functional understanding on par with function lessons. Regarding mechanism questions though, 6- & 7-year-olds resembled adult predictions: learning function did not facilitate mechanistic understanding. 8- & 9-year-olds, however, more closely reflected children's intuitions: even participants in the Function lesson condition performed above chance on mechanism questions, albeit worse than participants in the Mechanism lesson condition.

Taken together, these findings suggest that children's divergent intuitions may be consequences of their experiences: for child-directed explanations, function and mechanism may be mutually inferable and, so, children may have only a weak signal as to whether one knowledge type is typically prior to another. Children demonstrate a nuanced epistemic understanding in their belief that mechanistic knowledge represents a larger magnitude of knowledge than functional knowledge, thus it seems insufficient to endorse the deflationary account that Study 2's non-preferences are the result of too complex a demand. However, future work must confirm that children are able to make such epistemic inferences.

The current studies present novel insight into children's intuitions of the cognitive structure of function and mechanism. While historically people's experiences, such as satisfaction of learning, have not consistently predicted actual learning outcomes (Liquin & Lombrozo, 2022; McCarthy & Keil, 2023 with McCarthy et al., 2024), here children may offer unique predictive power in capturing the nature of their own learning. Future work might consider from where children develop these intuitions. Further, pedagogical work might consider whether explaining in accordance with children's intuitions, rather than those of adults, might foster more positive outcomes for learners.

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