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11 What Does It Mean to Engage in Scientific Thinking?

We began this book with a question: How do we bridge the gap between children's causal reasoning skills, which develop early, and their scientific thinking skills, which have a longer developmental trajectory? To answer this question, we first reviewed the causal graphical model framework, which provides a more precise way of describing how children represent causal knowledge and engage in causal reasoning. We then focused on two facets of scientific thinking: (1) how causal reasoning, particularly in context and combined with metacognitive development, forms part of the foundation of scientific thinking, and (2) how an explicit understanding of science, which potentially allows children to appreciate that they are doing science, relates to children's scientific thinking. We believe each of these processes is necessary for the development of scientific thinking, that neither alone is sufficient, and that these processes have similar but mostly independent developmental trajectories.

We briefly review those conclusions below, but first we want to note that our original concept for this book was to talk to different audiences—not only to researchers in our home field of cognitive development, but also to researchers interested in science education, to educators, and to the field of psychology more generally. In closing, we want to acknowledge that this book is merely a starting point. For example, many researchers are interested in the causal graphical model framework used to represent causal reasoning, which we sketched out in part I of the book. There are more detailed descriptions of that framework, many of which are specifically geared for researchers who want to build computational models. Our goal in including a brief overview of that work here was to articulate the idea that theories of development could be formalized. This provides great advantages because

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those formalizations make predictions about how reasoning occurs. But this approach also has limitations: Not everything fits into a nice, neat computational framework. Some of the unanswered questions about rational constructivism are difficult to incorporate into such a computational framework, such as the role of culture or parent-child interaction. These concerns operate in the other direction as well, in that there is a strong possibility that the field of artificial intelligence can be positively influenced by gaining a greater understanding of child development. Knowing more about how children learn might provide insight into how computers or robots could learn.

Similarly, one might object to our approach by claiming that experiments that use a blicket detector or other minimally contextualized methods are not studying scientific thinking. The most extreme version of this view is that scientific thinking can be studied only in a classroom or a lab, and it can include information drawn from only a particular set of topics. While we disagree with this extreme view, we do take to heart this general criticism, which was a primary motivation for the design of the studies presented in part II of the book. Our goal in detailing that work was to articulate the foundations of scientific thinking and to illustrate how one might bridge the gap between research in cognitive development and scientific thinking. The conclusions from those studies can apply to aspects of teaching science, as we discuss below, but they also embrace the idea that scientific thinking is all around us in our daily lives. Additionally, and importantly, we intended that work to serve as just one set of examples of what the two fields can learn from each other; much more work needs to be done to continue building that bridge.

Finally, one might object to our general approach of asking children questions about how science or learning works. These tasks are artificial and strange. We do not disagree; our goal with that line of work was to get researchers, educators, practitioners, and parents (basically, adults) thinking about these concepts. We often read academic research papers on science and learning that define these terms in the ways that adults (particularly academic researchers) think they should be defined; children's behaviors and thoughts are then judged through that lens. Asking children to define a concept like "science" possibly gets them to think about science, but also gets us as consumers of this kind of research to think about what science is as well, which hopefully makes us better, more open-minded consumers of science. But we also acknowledge that science is culturally constructed, and interviewing children across different cultures about science and other concepts related

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to learning (something we did not investigate) would be an interesting and important future direction.

Most importantly, as reflected in the quote from Carl Sagan at the start of chapter 1, our investigations and interpretations of children's causal reasoning and scientific thinking are fallible. If they weren't, we would be poor scientists. This is all to say that this book is a first step. We assume that few people will be completely satisfied with what we have written or how we have framed these investigations. We certainly are not. Not only because we have so much left to learn, but also because there are so many more ways in which we can try to strengthen the connections between causal reasoning and scientific thinking, and so many more ways in which we can apply what we have learned to help create a more scientifically literate society.

Causal Reasoning as a Foundation for Scientific Thinking

In part II of the book, we reported on a series of empirical studies that provide examples of how to explain the gap between work on young children's understanding of simple, less contextualized causal systems and work on older children's thinking about complex and scientifically rich causal systems. Preschool-age children, and possibly also infants, have some of the foundation for scientific thinking from their causal reasoning capacities, but these capacities undergo further development during the early elementary-school years, and likely beyond. Specifically, young elementary-school children are developing capacities to diagnose the structure of complex causal systems, to account for uncertainty in these systems, to engage in explicit belief revision when confronted with counterevidence, to incorporate aspects of their developing metacognitive abilities, and to recognize and design unconfounded experiments on these systems. Rapid maturation in these capacities seems to occur between the ages of 6 and 8, as children become increasingly able to think about systems with multiple variables, even when the specific efficacies of some of those variables are unknown. These developments occur at the same time as children's developing understanding of interpretive (or advanced) theory of mind, one of the component abilities of which is navigating disagreements between conflicting beliefs.

So while the processes involved in mature scientific thinking have their roots in early causal reasoning abilities, the development of these processes is not complete during the preschool years. Indeed, this development can

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be influenced by children's experiences in school, as our investigation of the effect of different curricula in the Springfield School District demonstrated (chapter 7). That is, preschoolers may be little scientists, but they also have much science left to learn. This is true not just with respect to acquiring knowledge about scientific content, but also with respect to how to go about doing science.

And this is perfectly fine. Much research in our home field of cognitive development has focused on young children and infants, aiming to chart the origins of various thinking processes. But this work can assume that it is sufficient to show that some abilities are present early in life, hence researchers may underestimate the importance of later developments in these abilities. Infants and young children have the foundational abilities to do science, abilities that allow them to systematically investigate and make sense of their world. As they develop, both their growing knowledge and their growing repertoire of skills shape the trajectory of how they are able to learn and express new scientific thinking abilities.

Explicit Understanding of Science

We have also traced the developmental trajectory of children's explicit understanding of science and related concepts like learning, play, and pretending. This line of work found that younger children tend to hold a content-based view of these concepts, swayed by these activities' visible markers and by the outcomes of the actions involved. As children get older, they incorporate a more mentalistic understanding, recognizing the roles of intentions and beliefs in all of these concepts. For example, younger children tend to view science only as a particular set of topics. Starting between the ages of 6 and 8, they begin to recognize that science is also a way of learning. We see similar development in children's understanding of learning and teaching, although the explicit understanding of each of these concepts matures with different developmental trajectories.

Across the book, but particularly in chapter 1 and chapter 8, we also outlined why we think that children's understanding of science should relate to their scientific thinking. Briefly, inspired by arguments from Kuhn (e.g., Kuhn, 1989, 2007a, 2011; Kuhn & Pearsall, 2000), we suggested that children who conceptualize science as involving reasoning and learning might be better able to marshal their developing scientific thinking skills in

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service of solving a task than are children who believe that science is merely a set of topics. These latter children might fail to understand the connection between their scientific abilities and the task at hand, and hence might not perform as well on the task. Briefly, if you do not think that a problem requires scientific thinking, you might not think about it scientifically.

The first time we tested this hypothesis, we indeed found a robust relation between children's definitions of "science" as a process of learning and their success on our diagnostic reasoning measure from chapter 5 (as we reported in chapter 8). This inspired us to continue our investigations, aiming to reproduce this initial effect. But as we conducted more research, we found that this relation was weaker and more complex than we had expected.[1] We found only marginal relations between children's definitions of "science" and performance on various diagnostic reasoning measures in a follow-up study, and there were some occasional connections between these definitions and children's performance with other measures of scientific thinking in our museum-based work.

Frankly, we can talk about this case as a process of our own belief revision. The fact that we did not directly reproduce our original result suggests that our hypothesis might be incorrect or that it needs to be modified to say that the effect is weaker than we initially expected. We believe that an explicit understanding of science is an important facet of scientific thinking. But, like belief revision, understanding uncertainty, or learning how to reason within complex contexts, it may have its own unique developmental trajectory, just like the other members of the family of abilities that make up scientific thinking.

For example, aspects of children's definitions of "science" related to their exploratory behaviors with a museum exhibit on gears (Callanan, Legare, Sobel et al., 2020): Children who defined science not as a specific activity and those who defined science as related to learning were more likely to engage in the systematic exploration that related to their causal knowledge. Similarly, these definitions related to how children played with an exhibit on electric circuits: Children who defined science as something that they themselves do or enjoy made more connections or disconnections among components in the process of building a circuit during free play with their parents (Sobel, Letourneau et al., 2021). While the frequency of their own actions during this free play session did not relate to their ability to solve challenges on their own, understanding science in terms of a personal connection did

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seem to give them a sense of agency in completing play-related goals during play with their parents.

Why this might happen is not clear—after all, neither of these latter studies were designed to investigate the question of how children's explicit understanding of science might relate to their scientific thinking abilities. But it is possible that certain aspects of our hypothesis hold true. One possible way to reconcile all these results is to say that the relation between children's ability to define "science" and their causal reasoning is weak when they are asked to reason about information generated by others. That does not mean that the relation does not exist. It means that there is still an effect worth investigating and describing, but the relation is complicated. When children are in control of their own behavior, their understanding that science is a learning process might indeed provide them with more opportunities to learn from play. Autonomy is important to children's reasoning, and this is something that we as a field need to consider in more detail.

Perhaps we should not be surprised that these relations are complex. As we saw in chapters 9 and 10, an explicit understanding of learning is not necessary for children to learn and an explicit understanding of pretending is not necessary for children to pretend. The explicit understanding of a concept might help children only to engage in metacognitive inferences related to that activity, but not to engage in the activity itself. For instance, as we reported in chapter 10, children's definitions of "pretending" related not to how they recalled engaging in pretend play, but rather to their judgments about pretense based on the metacognitive inferences they had to make about others' mental states. That is, there is likely still an important role for children's developing awareness of science as an active process of learning in their development into fully-fledged scientific thinkers, but this relation may occur for aspects of their scientific thinking other than their first-order abilities to solve diagnostic reasoning problems.

Constraints and Enabling Conditions: Relations among Knowledge and Skills

Another theme that we have considered throughout this book is how different aspects of children's developing knowledge and skills relate to each other and work together to reveal or suppress aspects of children's scientific thinking. We first introduced this idea in chapter 1 with reference to how

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children's theory of mind constrains their performance on other tasks, such as how they use what they know about others' beliefs to appreciate whether a character has learned something.

A similar example of the role of underlying capacities relating to children's cognition can be found in the potential relations between infants' motor development and their causal reasoning, as reviewed in chapter 3. Infants might initially represent causality as statistical regularities among events, and that statistical learning is motivated by their social interactions and their attentional capacities (e.g., Wu & Kirkham, 2010). As their motor capacities develop, this expands what information becomes available to them and also changes what kind of data they can produce. They can begin to do more than just actively interpret their observations; they can intervene to generate new information (remember how infants knock stacks of objects over to learn about how objects behave, but also possibly about how grownups react?). These developing capacities to intervene on their environments in increasingly complex ways might in turn change the way that infants represent information. This example also illustrates the vital importance of children's active interactions with their environments; learning to act on the world might affect how we represent it. An important facet of the causal graphical model framework as a description of how children represent causal knowledge is precisely that it values the role of action—intervention—in the development of children's reasoning abilities.

To take a more cognitive example, throughout the preschool years, the development of a variety of domain-general capacities can constrain and facilitate aspects of children's causal reasoning. As we discussed in chapter 10, children's pretend play, which emerges during the second year of life, can indicate that children have the representational capacities necessary to put aside one representation and reason about another (e.g., Leslie, 1988). Such representational capacities might be the basis of children's counterfactual reasoning. Counterfactual reasoning requires a representation of the specific causal structure one is reasoning about, as well as more domain-general imaginative capacities to represent a copy of that model, on which a hypothetical intervention is performed to represent the "what if" statement. Possessing domain-specific knowledge about the causal structure and possessing domain-general representational capacities, including the imaginative capacity and the cognitive control to act on the represented structure, are both necessary for counterfactual reasoning, but neither alone is wholly sufficient.

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Developments in other aspects of children's cognition thus first constrain and then facilitate children's causal reasoning. What is interesting about this hypothesis is that it offers an analogy for our take on the relation between causal reasoning and scientific thinking. Specifically, having the capacity to engage in causal inference is necessary but not sufficient for fully engaging in scientific thinking. Beyond the ability to represent causal relations, one also needs to be able to change one's beliefs and understand the conditions under which such belief change is warranted. The latter involves not only learning from sets of data, but also being able to recognize when one is wrong; articulating different beliefs in light of new information is at the forefront of scientific thinking. Belief revision also involves more domain-general processes, such as cognitive control, that are also necessary to inhibit the complex or unfamiliar ways in which a problem is phrased in order to recognize its underlying causal structure. But even though the capacity to reason about causes and the ability to represent events in terms of their causal structure do not reflect the entirety of scientific thinking, they serve as its foundation. They allow children to integrate the data they observe and draw conclusions about it, which forms an important part of scientific thinking, even if not its entirety.

As we have documented, the many cognitive and metacognitive capacities involved in scientific thinking have distinct developmental trajectories between the preschool and elementary-school years. But each of these capacities also imposes constraints on children's abilities to progress in their development of scientific thinking abilities. Lacking the knowledge of how a particular domain of science works (e.g., biology) can affect children's abilities to reason about that domain (e.g., whether a character ever needs to sleep), even if they may be perfectly capable of drawing parallel inferences for a different domain (e.g., whether an object can float in the air). On the flip side, possessing such knowledge does not automatically guarantee that children will be able to draw appropriate inferences; it merely sets up the enabling conditions for their potential reasoning.

Further, and somewhat speculatively, the idea that domain-specific knowledge constrains some of our domain-general capacities, like causal reasoning, can also potentially explain why gaining metacognitive insight into these capacities is so difficult. If our causal reasoning abilities and scientific thinking abilities are constrained in different ways at different times by domain

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knowledge and by the development of other abilities, then it stands to reason that it would be more difficult to understand the inner workings of these capacities than to understand the nature of our content knowledge or of other aspects of our thinking.

It is this intricate interplay between children's knowledge and skills and the ways in which these aspects of their cognitive capacities constrain each other that we wish to ensure is part of the conversation about how children's scientific thinking develops. Children's thinking is not fully domain-general; children are not necessarily able to express their skills fully in all circumstances as these skills are developing. There are effects of context, both cognitive and sociocultural, that influence children's performance on lab-based tasks and in school. Put another way, it may not make sense to ask *when* children become able to succeed at expressing a particular skill. Rather, our claims and conclusions must be sensitive to the larger developmental system within which children exercise their abilities.

Constructing Scientists

The work described in this book has been primarily concerned with charting how children's early abilities to solve simple and relatively decontextualized causal reasoning problems begin to develop into the skills that they will eventually need to engage in more complex scientific thinking. As we conclude, we want to consider how these findings could translate into recommendations for formal and informal science education. One straightforward conclusion from the work presented here is to focus more on children in kindergarten, first grade, and second grade. We have found shifts in children's performance on diagnostic reasoning tasks and in their definitions of "science" between the ages of about 6 and about 8. This period thus seems to be an important time for children (at least in our culture) to develop both their scientific thinking skills and their knowledge of what science is. In turn, this implies that interventions aimed at boosting scientific thinking in this age group may be particularly successful.

Formal Learning Environments

It is crucial to note that children enter school already in possession of powerful causal reasoning mechanisms. This argument has been made before

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with respect to children's knowledge of the content of scientific theories, because even preschoolers have rich conceptions of the biological, physical, and psychological world (see Carey, 2009; Inagaki & Hatano, 2006; Shtulman, 2017; Vosniadou, 1994). Teachers who view their students as blank slates are thus fighting an uphill battle, as they attempt to get their students to learn things that contradict students' preexisting knowledge. For example, most kindergarteners believe that the Earth is flat, because of the way that it looks to them, and lessons trying to convince them that the Earth is round tend to be generally ineffective; they can even lead to further misconceptions as children try to integrate this new knowledge with their existing beliefs. In general, addressing the existing conceptions and misconceptions that children have, rather than ignoring them, paves the road for a better and more effective educational experience (see work on refutation texts in science education; Sinatra & Broughton, 2011; Tippett, 2010). Children learn with repeated exposure, but this takes effort.

Attempting to teach children about science without understanding their existing beliefs about science might be similarly ineffective. Gaining insight into how children conceptualize this topic can help us reach them where they are, rather than assuming that they will straightforwardly absorb our adult concepts of science. Similarly, children come to school already in possession of some abilities to reason about causal systems, which seem to be present in preschool (e.g., Buchanan & Sobel, 2011; Gopnik & Wellman, 2012; Schulz & Sommerville, 2006). Our work suggests that children in kindergarten and first grade are ready to advance these skills to more fully-fledged scientific thinking abilities.

Our work on children's definitions can also help us to understand how best to structure early science education. It is worth noting that our approach of asking children for explicit definitions of various concepts is a bit outside the norm, both in educational research and in our home field of cognitive development. There is some merit in that argument, as we noted in chapter 8, because children might not have good insight into the content of their own concepts. Nevertheless, we see value in our approach, both for basic developmental science research and for education. For one thing, we believe that this technique could be used fruitfully as a jumping-off point for understanding conceptual development. Using this approach, we have found many connections between children's definitions and their performance on various tasks, particularly within the domain of learning:

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Children who understand learning at a more mature level are also better able to reflect on their own learning. But even if such relations do not exist, that null finding provides interesting information about the link between children's abilities and their explicit knowledge in development. We can then ask when children become explicitly able to provide reasonable definitions for a concept and whether that ability seems to impact their performance related to that concept. We can also ask how the abilities that infants and young children possess implicitly come into conscious awareness, such that older children and adults can access and manipulate them explicitly. Finally, we can ask whether providing children with aspects of these definitions facilitate their performance related to the concept.

The answers to these questions have implications far beyond the development of scientific thinking. At the heart of this question is the issue of consciousness: What is the difference between possessing an implicit ability to perform some task and additionally possessing the explicit awareness that one is doing that task, or how one is doing so? Asking about children's definitions can thus be an important tool in the kit that we use to map the trajectory of the development of children's awareness and metacognitive abilities.

With respect to education, our work on children's definitions also suggests a potentially helpful shift in how science is framed in educational settings. Formal and informal learning environments tend to present children with "science classes" or "science activities"—but the mere act of calling some kinds of learning content or activities "science," while not applying this label to other things, might shift how children think about science. Specifically, it might lead children to think that science is only a particular set of content areas or a certain subset of activities. Broader actions that are clearly scientific (like asking questions and searching systematically for answers) might not be categorized as "science" by younger children. Indeed, our interviews found that the younger children we investigated tended to conceptualize science as a narrow set of topics. In turn, this may hamper their abilities to engage in scientific thinking on a wider variety of tasks. Much like telling children to "be scientists" (Rhodes et al., 2019), focusing preschoolers and young elementary-school students on the science corner of their classroom or separating science topics into their own class might discourage them from recognizing that they can engage in scientific thinking in other places and times.

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Our suggestion is to integrate science into early educational curricula in a more holistic way. While the practice of science does tend to concern itself with a particular set of topics and questions, at its heart, science is a method of investigating the world. This method involves gathering evidence for one's claims, thinking critically and carefully about this evidence, weighing one's existing beliefs against the strength of incoming information, and objectively navigating situations of uncertainty and disagreement, among other things. These skills should surely not be confined to a single classroom or to a brief experience, only to be left behind when children are engaged in literacy and math and social studies; these skills are ones that children will need to succeed in all aspects of their lives.

This is not necessarily how early science education occurs, at least in the United States. Science is often presented to young children as a topic or activity, and it is confined to a (shockingly brief) period of time in the school day (particularly compared to math or language arts). No wonder many of our younger participants claimed that science was only about dinosaurs or potions. Some schools are beginning to address this issue by including more scientific content in nonscience times in the curriculum, as when literacy lessons focus on reading science texts. We would argue that this is a good beginning, but also that science needs to be more fully and deeply integrated into all aspects of education. More specifically, the skills of scientific thinking should be treated the way that current curricula treat the skills of literacy. Reading is a skill that children must master, not merely for its own sake, but in order to engage with any kind of content across the curriculum (e.g., social studies, math problems) and to succeed in adult life. Scientific thinking is also a set of skills that children must master in order to think clearly about topics across the curriculum and to succeed in adult life. By respecting children's existing abilities in scientific thinking, and then by engaging with both these developing skills and with their explicit knowledge, we can make real progress on teaching science to the youngest learners.

One additional message of our work is to focus science teaching not just on the content of science or on science facts but on the nature and practice of science. This recommendation is at the core of new guidelines for science teaching (e.g., the Three-Dimensional approach in the Next Generation Science Standards; see NGSS Lead States, 2013; National Research Council, 2012), and our work strengthens the basis for this recommendation.

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Specifically, we have argued that a broader conception of science (as a process of learning, rather than as merely a set of topics) has links to children's abilities to reason scientifically. While our evidence for this connection in childhood is tentative and requires further investigation, this is more strongly the case for adults: Adults who have a more accurate view of how science is practiced are more likely to accept scientific claims (Weisberg, Landrum et al., 2018, 2021). It is possible that teaching students how science can create knowledge and that science involves active processes of learning and discovery could help underpin their abilities to think scientifically.

In general, then, science is not a topic of study that should be done only in a particular place or at a particular time. Science is a set of skills that apply in myriad circumstances in our lives. Integrating scientific thinking broadly across the curriculum may well be the key to nurturing young children's causal reasoning abilities to fully bloom into mature capacities for scientific thinking.

One other facet of children's understanding is important here. Children's identities—particularly as learners—are constructed over time and based on their experience. Identity-based language, such as "let's be scientists," can suggest to children that "scientist" is a social group, and that only some people are members of that group. This can lead them to interpret any failure at a science task as a sign that they are not members of that group, in turn leading them to persist less on challenging topics and problems. In contrast, the action-based language of "doing science" suggests to children that they are engaged in a set of activities. If they are challenged under these circumstances, instead of interpreting the struggle as a sign that they lack the qualities of a scientist, they may be more likely to interpret this struggle as situational and not specifically about them as learners (Archer et al., 2010; Rhodes et al., 2020). So, when integrating scientific thinking into the classroom environment, introducing this kind of thinking as an action as opposed to an identity might promote greater engagement with the material.

Informal Learning Environments

Many facets of our thinking about children's development have been inspired by our collaborations with informal learning institutions. Although interactions about science can happen anywhere, we focus here on museum settings because they offer the ideal environments to consider how children engage

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in various aspects of scientific thinking. Museums are designed to promote learning through active experiences, and they integrate a diversity of authentic activities and interactions, providing information that children can use to engage in belief revision and learning about science.

Dave's lab has worked with Providence Children's Museum for about seventeen years, while Deena's lab has worked with the Academy of Natural Sciences for about eight years. In general, academic researchers and informal learning institutions can partner in a number of different ways, often to mutual benefit (Callanan, 2012; Sobel & Jipson, 2016). Critically, working in informal learning environments allows researchers to document how children can learn from everyday experiences, including from their observations within the museum environment and from their interactions with the exhibits and with other people (e.g., caregivers, siblings, peers, museum staff).

The two primary museums with which we collaborate have different pedagogical goals. Providence Children's Museum believes in the importance of play for the developing child—not just their cognitive development, but their social-emotional and identity development as well. Mind Lab, the program that Dave helped establish with the museum staff, focuses on learning about how children (particularly young children) learn, and not about any particular scientific content. Indeed, the majority of the work on children's understanding of learning, teaching, and play described in chapter 9 emerged from a collaboration with members of the museum staff. In contrast, the Academy of Natural Sciences is a natural history museum with the mission of helping visitors to understand the natural world and to feel inspired to care for it. While the Academy has a dedicated children's exhibit, called *Outside In*, the majority of the museum caters to a broad audience across the age spectrum.

To investigate the role of these different missions more closely, we are currently conducting studies that compare children's exploration, reflection, and learning across these two museums. As an example of some of our preliminary results, we (Stricker & Sobel, 2021) tested 120 children between the ages of 6 and 9 (62 girls and 58 boys; mean age = 94.92 months; age range: 72–119 months) on their conceptions of learning. Half of the children were tested at Providence Children's Museum after they had engaged in free play at a set of exhibits, where they had the opportunity to choose where to go and what to do. After their exploration and play, children were tested on a short experiment. The other half of the children were tested in the lab, where they

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did not have an exploratory play session, although they were given a similar experiment. We then introduced both groups of children to a picture of a novel toy (based on Bonawitz et al., 2011). The toy had a number of different manipulanda, and it was not clear what the toy did or how it worked. We told the children that this toy could do a lot of things, and we asked children how they wanted to learn how the toy worked: by playing with it themselves, by asking their grown-up, or by watching someone else play with it.

Overall there was a difference in the distribution of responses between the two environments.[2] In both conditions, the most frequent answer was to play with the toy, but this answer varied between the conditions. Forty-seven percent of the children in the lab chose to learn about the toy by playing with it themselves, while 63% of the children tested at the museum did so. In contrast, 35% of the children in the lab chose to ask their grown-up, while only 20% of the children at the museum did so. Choosing to watch another child didn't differ between the two environments (18% in the lab vs. 17% at the museum).[3] Overall, these data suggest the possibility that the environment in which children are tested affects how they might respond to experiments and interview questions.[4]

Related to this finding, however, is the possibility that how children engage in scientific thinking differs depending on the context they are in. In particular, consider our own findings on the relations between children's definitions of "science" and aspects of their scientific thinking. The first experiment where we asked children to define "science" and then related these definitions to their performance on our diagnostic reasoning measure was done at Providence Children's Museum. Recall that in this sample, we found this hypothesized relation, which held even when controlling for age. We similarly found effects of children's conceptualization of science and facets of their exploration at Providence Children's Museum and in other children's museums around the country. But we did not find this relation when we tested children in schools, in the laboratory, or at the Academy.

It is possible—and this is a hypothesis we would like to investigate further—that children's access to their scientific thinking differs across these contexts. Places where children are explicitly aware that they are doing science, like schools or museums with a scientific focus, implicitly encourage children to bring their developing scientific thinking to bear on tasks. When children are tested in these settings, they might be already primed to do science, thus lessening the impact that their own definitions of "science" might have on

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their task performance. But when children are tested in environments where science is not necessarily part of their perception of this environment, like a children's museum that does not focus on science content, there might be more scope for children's own conceptions of science to play a role in their task performance. Specifically, they might engage in scientific thinking in these environments only if they conceptualize science as being generally related to learning. Indeed, as noted above, we did not see a relation between children's definitions of "science" and their diagnostic thinking in the data sets that we collected at the Academy or in the Springfield School District. But we did see this relation in environments that were focused more on play and learning, which did not necessarily have the pedagogical goal to teach scientific content.[5]

Taken together, these findings invite us to deepen our understanding of how formal learning environments, informal learning environments, and everyday experiences contribute to the development of children's scientific thinking skills. Cognitive development does not happen just in the laboratory; its findings must generalize to classrooms, museums, and everyday interactions with the world. Similarly, science learning does not happen just in the classroom; its practices and processes can be found throughout children's lives. We hope that our work can help to illuminate how this learning happens, allowing all children to reach their potential as scientific thinkers.

What Constructing Science Means

While we like the play on words in the title of the book, we need to conclude by clarifying a possible misconception that this title might raise. "Constructing science" implies an end state—that there is a point in development where children become capable of scientific thinking. But scientific thinking develops throughout the lifespan, beginning with children's causal reasoning abilities and continuing throughout adulthood. Young children are already on that journey; they are learning the skills necessary for scientific thinking and are learning to apply such skills across many situations. But if even children have access to the rudiments of scientific thinking, and if these skills continue to develop over the course of their lives, then why are we not a more scientifically literate society?

While there are many influences on adults' scientific beliefs and their abilities to apply their own capacities for scientific thinking (e.g., Angier, 2007;

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Weisberg et al., 2021), based on our own work, we suspect that one additional answer to this question has to do with the metacognitive awareness that is necessary for scientific thinking. Not only is scientific thinking complex in its own right, requiring coordination with multiple other cognitive skills, scientific thinking also may require insight into one's own thought processes. This alone may make aspects of scientific thinking difficult to achieve. As an analogy, consider the process of learning to drive a car. This is a skill that is somewhat difficult to learn (and that, like scientific thinking, requires the coordination of multiple cognitive skills as well as some social interaction). Eventually, though, it becomes automatic. But this automaticity may get in the way of metacognitive awareness; trying to explain to someone else how to drive a car or trying to become consciously aware of our own actions as we are doing so becomes increasingly difficult. Scientific thinking might be similar. Recall that most adults responded to our diagnostic reasoning measure in the way we had intended (following the logic of interactive causality), but a subset of them could not articulate the reasoning behind their choice.

The need for metacognitive awareness thus might be part of what makes scientific thinking difficult for adults, or at least more difficult than the causal reasoning capacities that even young children seem to possess. A better analogy, then, may be that causal reasoning is like learning to drive a car, while scientific thinking is more like learning to fly a plane. Many adults learn to drive a car, just as young children develop a causal reasoning system, potentially from lower-level mechanisms of statistical regularity. Driving is something that so many people learn to do, it is almost considered a rite of passage in our society. Learning to fly, however, is something that fewer people learn to do and, as such, seems more intimidating. But both skills are built up out of more foundational skills, and both skills, though difficult, can become automatic through practice and experience. The more we become aware that we are engaging in the kinds of reasoning and metacognition necessary for scientific thinking, the easier it will become for us to do so. So, to make one last *Star Trek* reference, let's fly.

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Constructing Science

Connecting Causal Reasoning to Scientific Thinking in Young Children

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