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5 A New Blicket Detector Task

The rational constructivist framework that we reviewed in part I of the book takes seriously the idea that children are little scientists (Gopnik et al., 1999). But if this is the case, when and how do they become able to explicitly form hypotheses, revise beliefs, and collect and interpret data? Answers to this question have been elusive. Although we have argued that children's learning is well-described by the causal graphical model framework, which has been incorporated into the rational constructivist view of development, these theories are not yet full descriptions of how learning and development work (as discussed in chapter 3). Most relevantly for our purposes, there is a disconnect between work on children's causal reasoning abilities, which seem to develop early and which arguably underlie the processes involved in scientific thinking, and work on children's later-developing scientific thinking abilities, which documents children's struggles to think about more complex and realistic scenarios (as documented in chapter 4). In this chapter we present an empirical measure that begins to reconcile some of these disparate sets of findings. In the remainder of part II, we employ this measure in several studies investigating how children's causal reasoning abilities provide a basis for their developing abilities for scientific thinking. Importantly, these studies are meant to illustrate how we might bridge the gap between causal reasoning and scientific thinking, and thereby identify some of the important developmental changes that are required to link these two sets of abilities. These studies, however, do not present a definitive or unique way to do so.

As we reviewed in chapter 4, many variables differ between tasks designed to study children's precocious causal reasoning and tasks designed to study children's scientific thinking. And, despite their similarities, there are also

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many differences between causal reasoning and scientific thinking. Given this, as noted above, our goal with this new empirical measure is simply to provide one potential bridge between these abilities, one way to begin to address the complexity of these issues. To do so, we focus on two of the variables identified in chapter 4: age and causal complexity. First, in terms of age, we use a task that can be understood by younger children, but that is still difficult enough to present a challenge to children at a wide range of ages. We are thus able to administer exactly the same measure to children in preschool and in elementary school, as well as to adults. This consistency allows us to track the emergence of diagnostic reasoning abilities over time.

Second, as is common in work on older children's scientific thinking abilities, our task presents a complex causal system. It includes four potential causes, each of which could be in one of two possible states, and there are three possible effects in this system. This is a major departure from traditional work on causal reasoning, which typically focuses on a smaller number of potential causes (usually two) and outcomes (usually the presence of absence of one). Further, the structure of the causal system is interactive: Two of the causes separately have one effect, but jointly they create a different effect. This type of system resembles much more closely the messiness and complexity of real-life scientific problems and of the tasks designed to capture these problems. Indeed, we based this structure on ones instantiated in investigations of scientific thinking (e.g., Dean & Kuhn, 2007), though with somewhat fewer potential causes and effects, to make it easier for our youngest participants to grasp. In addition, our procedure for demonstrating this system presents combinations of causal factors and does not show the effect of each cause in isolation. Participants thus have to manage some degree of uncertainty and draw inferences from the sets of data that they have observed to determine how the system works.

However, as in standard work on causal reasoning, this system does not present any explicitly scientific content (though it can be used to do so; see chapter 6). Specifically, it uses a procedure with a novel blicket detector, in which colored blocks are placed on a machine in various combinations. Our choice to maintain the minimal contextualized nature of this task, at least for these initial studies, is deliberate: We want to test how children perform with a higher degree of causal complexity before additionally examining their abilities with real-world scientific content.

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In addition, rather than asking participants to explore the system for themselves, we present them with sets of data that we constructed. We also ask them to select an answer to our test question rather than to generate one themselves. These design choices are again more in line with work on causal reasoning than with work on scientific thinking, which puts more of an emphasis on children's own exploration of a system. Again, we chose this method of presentation primarily to bring the task within the reach of our preschool-age participants, because it might be easier for children to demonstrate their causal reasoning abilities by recognizing a correct answer that is presented to them. Additionally, as we saw in chapter 4, there will likely be differences in how different children interact with the causal system, which could in turn affect the inferences that different children are able to make; as we've discussed, children's exploration of causal systems is influenced both by the social nature of the interactions around these systems and by the efficacy of their actions on these systems. We want to ensure that all participants observe the same set of data, so that we can describe how children across a range of ages respond to exactly the same task. Of course, this same causal system could be presented as an exploration task; we are aiming to do this in future work. For now, let's meet this new blicket detector task and see how children (and adults) respond to it.

How the Task Works

Our new task begins with an experimenter presenting the blicket detector to a participant. This version is a battery-powered black box with a translucent white pressure-sensitive plate on top (see figure 5.1). The pressure-sensitive plate really works, so that the machine activates when something is placed on top of it. Like the blicket detectors we have already described, though, the actual activation of the machine is a magic trick—any object that pushes down the pressure plate can make the machine go. The pressure plate is controlled by an enabling switch on a remote. The colors of the lights that are displayed through the translucent top are also controlled by the remote, which is operated by an experimenter out of sight of the participant.[1]

The experimenter explains that the box sometimes lights up and plays music when blocks are placed on it. She then introduces a set of four blocks, all identical in size and shape but different in color. To illustrate the task,

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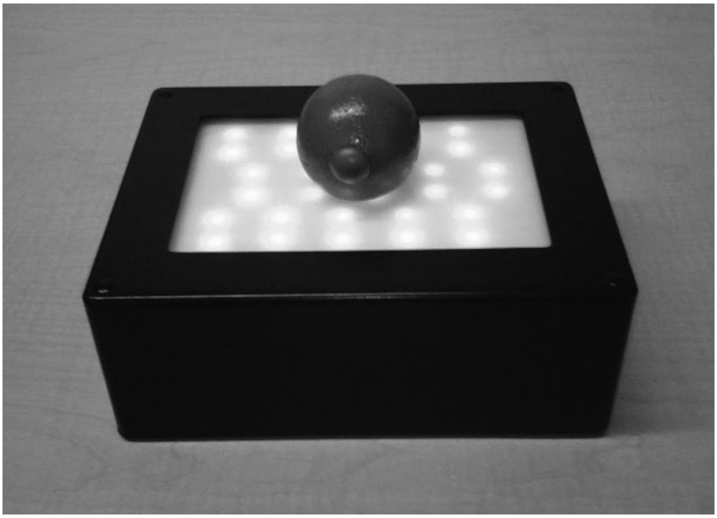

Figure 5.1
Blicket detector used in the experiments described in this chapter. This detector could activate two different ways—green or red. Each activation played a unique song.

we will describe one version that we ran, using rectangular prisms that were yellow, black, orange, and blue. The exact shape or color of the blocks do not really matter, though it is important to ensure that there is no connection between the color of the blocks and the color of the lights on the machine. This way, participants will not be able to assume that a green block is responsible for making the machine light up green, or that a yellow block and a blue block together are responsible for making the machine light up green. Further, the blocks are put inside a clear plastic container before being placed on the machine so that they all appear to contact the machine at the same time. Again, this ensures that no causal factors appear to be responsible for making the machine light up other than the combination of colored blocks.

The experimenter demonstrates how the machine works by first placing all four blocks (yellow, black, orange, and blue) into the container and putting the container on the machine. The machine lights up green and plays a song (e.g., a MIDI version of *Fur Elise* or "Twinkle Twinkle Little Star"). This is demonstrated a second time, and the experimenter narrates what is

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happening: "See, the machine is turning green. When I put all four blocks on the machine, it turned green." The experimenter then places a photograph of the four blocks on the table next to the machine, accompanied by a green dot, explaining, "I'm going to put this green dot here so that we can remember what happened. When I put the yellow block, the black block, the orange block, and the blue block on the machine, it turned green." This ensures that the task places few memory demands on participants; they can always refer back to the reminder cards on the table to tell them about the events that they saw.

Then, the experimenter places three blocks inside the container: the yellow one, the black one, and the blue one. When these blocks are placed onto the machine, it turns red and plays a different song. As before, the experimenter demonstrates this twice and narrates her actions ("Look, it's turning red!"), and places a photograph of these three blocks on the table with a red dot as a reminder.

The third event is similar to the second, except that this time the yellow, black, and orange blocks are placed on the machine together. This combination also makes the machine turn red and play the second song. Another reminder card with these objects and a red dot are placed on the table.

Finally, the experimenter places just the yellow block in the container and puts it on the machine. Nothing happens. This is demonstrated twice, to ensure that the participant knows that it is not an error, and the experimenter verbally reinforces the fact that the yellow block does not activate the machine. The experimenter then places a photograph of just the yellow block on the table with no accompanying colored dot.

This is the end of the data-presentation part of the task; participants have now seen four different combinations of blocks and three different outcomes.[2] We then test children's ability to diagnose the causal structure of this system. To do so, the experimenter puts up a cardboard barrier, blocking the participant's view of the blicket detector and the blocks. The experimenter tells the participant that she is placing two blocks on the machine, and she reports that the machine lit up green. In reality, to avoid providing any visual cues as to which blocks were used, the experimenter merely presses down the pressure-sensitive plate without moving the blocks from their position on the table. Participants can confirm for themselves that the machine turned green because they can hear the music that was associated

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with the green light. They can also see the green light from the detector illuminate the experimenter's face. The activation stops and the experimenter then removes the barrier to reveal the machine and the four blocks. Then, the participant is asked the test question: "Which two blocks did I place on the machine to make it turn green?" To make this question a bit easier for child participants, we present it as a multiple-choice task rather than as an open response. All participants are asked to choose an answer from among three possible pairs: black and blue, black and orange, and orange and blue. Photographs of each of these options are placed on the table in front of the participant, and the experimenter asks them to choose which pair made the machine turn green.

We considered the correct answer to the test question to be the orange and blue pair. Here's our logic: The yellow block is not efficacious (and also not part of any of the test options), so it can be discarded from consideration. Participants have already seen that the combination of black and blue and the combination of black and orange make the machine turn red. The only time that they see the machine turn green is when the blue and the orange blocks are placed on the machine together (though this was only ever done in combination with the other two blocks). For the purposes of scoring participants' performance on this task, we label the choice of the orange and blue pair as correct and the choice of either of the other two pairs as incorrect.

Importantly, the data that we presented in the demonstration phase involved one, three, or four blocks, but the test question asks participants to reason about a situation they have not seen: the effect of two blocks on the machine. Participants must extrapolate from the events that they have already observed to draw conclusions about a new situation. This task provides them with enough information to do so, but not in a way that makes the conclusion obvious.

Moreover, there is a relation between the structure of this task (multiple potential causes and multiple possible effects) and the interactive causality observed in measures of scientific thinking. Yellow and black are inefficacious. Blue or orange are efficacious and individually make the machine turn red, but together change the nature of the effect (the machine turns green). This is similar to the kind of diagnostic inferences children have to make in some of the scientific reasoning measures we discussed in chapter 4. Fundamentally, this procedure examines whether children have the

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diagnostic reasoning capacity to engage in the kinds of inferences required in measures of scientific thinking.

So how do participants respond to this task?

Adults' Performance

When we started this project, we initially presented it to our colleagues around our two departments. All of these trained scientists got the answer correct, although only some of them could articulate the logic behind their choice; several admitted they were guessing. But to provide a more formal anchor against which to compare the developmental data, we recruited 40 undergraduate students from a psychology participant pool (28 women; mean age = 20 years and 0.8 months; age range 18–27) and presented them with the task that was just described. Thirty-four of these 40 students, or 85%, answered the test question correctly. This is significantly greater than chance performance (33%, because there are three answer options presented)—but, interestingly, it is not at ceiling.

We also asked these participants to justify their answer choices. Many of them were able to describe the logic of the task correctly. For example, one student said, "I discounted the black because it's present in all three [options], so that's left me with these two [orange and blue]." Another student reasoned similarly: "In the one where it lit up red, the orange was present by itself, and then the blue was present by itself, but then when both the orange and blue were present, it made green." Or, more succinctly, "Because the combination of blue and orange isn't in the ones that make it red."

It is worth noting, however, that even some of these college students who responded correctly to the test question were not able to justify their decision explicitly. In two cases, students answered correctly but then admitted to guessing or not knowing how the machine actually worked. For example, "It was just a guess, because you don't really have much information from the previous stuff about what would happen with two blocks as opposed to three or four."

Conversely, of the six students who answered incorrectly, some of them justified their decision quite logically. For example, one student chose the black and orange combination, saying, "I just kind of figured that each time it lit up with a black block, the black block was necessary for the box to light up. This combination without the orange was red, and for this one [all four

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blocks], black and orange went green." Some of these students also admitted to guessing, but in four of the six cases, they tried to justify their choice with respect to some combination of the blocks (although sometimes that justification led to a contradiction).

The overall picture, then, is that adults generally reason about this task in the manner we intended and can usually report on the reasons for their choice at test. This implies that adults are explicitly thinking through the task, which allows them to have access to their thought processes when we ask them to justify their choice. Is the same true of children?

Children's Performance

Our initial presentation of this task involved a sample of 72 children (see full report in Sobel, Erb, Tassin & Weisberg, 2017, Study 2). To look at developmental change, we divided our participants into two groups based on age. There were thirty-six 5- and 6-year-olds and thirty-six 7- and 8-year-olds.

Children in the younger group chose the correct response 39% of the time, which was no different from simply guessing (33%). However, children in the older group chose the correct answer 61% of the time, which was significantly better than just guessing. This level of performance was not quite as good as the adults', but it was significantly better than that of the younger children. These data suggest that the ability to reason about complex, but less contextualized, causal systems develops between the ages of 6 and 8.

We found similar levels of performance from a second set of 116 children (see full report in Weisberg, Choi & Sobel, 2020, Experiment 1). These children ranged in age between 4 and 10 years, allowing us to examine a wider spectrum of performance than before. We found that, overall, participants were 45% correct, significantly above chance. There was also a clear developmental trend: 4- and 5-year-olds as a group were 38% correct, 6- and 7-year-olds were 41% correct, and 8- through 10-year-olds were 55% correct. Again, these data show evidence of development between the ages of 6 and 8.

Additionally, we asked a subset of these participants ($n = 39$) to justify their choice following their response to the test question, as we had done with the adults. Many participants were unable to justify their responses coherently or simply said, "I don't know," while about 18% of children referred back to the data that they had seen and gave reasonable explanations for why

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they chose the answer option that they did. For example, one child said, “Because they [orange and blue] are the only two colors in this [pointed to the picture of all four blocks] when it turned green.” Although justifications with this high level of maturity did not appear particularly often, it is noteworthy that children who provided justifications like this one tended to perform better on the task (86% correct) than children who provided other types of justifications (56%), although this trend was not statistically significant, possibly because the sample size was too small. But this pattern could suggest that one part of the developmental trend we are observing is a shift from using a more implicit method of solving this task to using a more explicit one. The latter method would allow children to align their response to the test question with the justification of their choice.

Further Uses of the New Blicket Detector Task

Our goal in constructing this new blicket detector task was to begin to reconcile the findings from work on causal reasoning in young children and work on scientific thinking in older children. This new task combines features from causal reasoning studies, such as the use of systems that lack explicitly scientific content and the role of experimenters in selecting and presenting sets of data, with the causal complexity of scientific thinking studies. Of course, this is just one possible way to more closely align the work from these two fields, and our results using this task should be taken as case studies of ways in which this alignment can happen, not as a definitive method of doing so.

Nevertheless, our findings with this task begin to suggest new ways to think about the development of scientific thinking skills. One thing that seems clear is that reasoning about this kind of interactive causal system in the way that we have described is challenging for the preschoolers we tested; only by about 6 or 7 years of age did children as a group begin to respond to this task at levels greater than expected by chance. This strongly implies that preschoolers’ success with tasks using blicket detectors (such as many of the studies described in chapter 2) is due, at least in part, to the type of causal systems that they are asked to diagnose with those tasks. Introducing uncertainty and interactive causality makes our task more difficult. There is thus evidence for a more protracted developmental trajectory for reasoning about these kinds of systems. This conclusion aligns with

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other work from our labs showing that preschoolers respond at chance levels about causal systems with uncertain causes until about age 6 or 7 (e.g., Erb & Sobel, 2014; Sobel et al., 2017) and that preschoolers' belief revision abilities are present but weak (e.g., Macris & Sobel, 2017).

However, this task in itself does not fully answer the question of when and how scientific thinking skills develop. For one thing, this system is mostly decontextualized; it lacks explicit scientific content. We take up the question of what happens when this type of content is introduced in chapter 6. In addition, it is still not clear exactly how children are solving this task and whether (and when) they are able to reason about it explicitly. Children's justifications indicate that at least some of them (and perhaps even some adults) may not have conscious access to the procedures they use when engaging in the diagnostic reasoning necessary to respond to our test question—even when they answer this question correctly. But, as noted in chapter 4, being able to explicitly reflect on one's own beliefs as one thinks about a causal system is a crucial part of scientific thinking. We address this connection to metacognitive processes in chapter 7.

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Constructing Science

Connecting Causal Reasoning to Scientific Thinking in Young Children

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