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"There Must Be a Cat Nearby": Kindergarteners' Reasoning About Action at an Attentional Distance

S. Lynneth Solis[1], Tina A. Grotzer[1] & Kaley N. Curtis[2]

[1] Graduate School of Education, Harvard University, Cambridge, MA, United States

[2] Department of Psychology, University of California Berkeley, Berkeley, CA, United States

Correspondence: S. Lynneth Solis, Harvard Graduate School of Education, Longfellow 420, Cambridge, MA, 02138, United States. E-mail: Lynneth_Solis@gse.harvard.edu

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Abstract

Action at a distance describes causal relationships in which causes and effects act at a distance. Many concepts in life and in science involve action at a distance, such as a remote control activating a television or magnets repelling each other without touching. Some forms occur within the same attentional frame, such as two magnets on a table, making it possible to observe the covariation relationships between them. Others occur at an attentional distance, obscured by space or other variables that make it difficult to perceive covariation. The term *action at an attentional distance* (A@AD) underscores this distinction (Grotzer & Solis, 2015). Previous research demonstrated that elementary students experience difficulties in interpreting A@AD but can reason about it through mediating mechanisms. The present study extended this work to characterize kindergarteners' reasoning about A@AD within familiar and unfamiliar contexts. Twenty-five kindergarteners participated in two interview sessions where they were presented with hypothetical scenarios and asked to reason about the possibility of A@AD. Results revealed that in certain cases young students accepted and described A@AD, and this was informed by their familiarity with the context, availability of possible explanatory mechanisms, access to covariation information, and attention to their own interventions.

Keywords: action at a distance, causal reasoning, early childhood, kindergarten, science learning

1. Introduction

Action at a distance refers to causal relationships in which causes are able to enact an effect without direct contact between causes and effects. There are many examples of action at a distance in everyday life offering children the opportunity to become familiar with the concept (e.g., Sobel & Buchanan, 2009; Spelke, Phillips, & Woodward, 1995). Children learn how remote controls activate televisions, lights, and air conditioners. They may play with magnets and observe one magnet repelling another despite a physical separation. The forms in these examples occur within the same attentional frame making it possible to observe the covariation relationships between them.

Covariation is a primary mode of causal induction and has been extensively studied in the developmental research, historically (e.g., Bullock, Gelman, & Baillargeon, 1982; Shultz & Mendelson, 1975; Siegler, 1976) and more recently in the form of Causal Bayes Nets and the statistical summing across of instances to discern possible connections (e.g., Gopnik & Schulz, 2007; Gopnik & Bonawitz, 2015; Griffiths, Sobel, Tenenbaum, & Gopnik, 2011; Young, 2016). This work suggests that very young children, as young as two and three years of age, are capable of reliably tracking the statistical regularities between co-varying candidate causes and effects to discern the possibility of a causal relationship (e.g., Bonawitz, Ullman, Bridgers, Gopnik, & Tenenbaum, 2019; Gopnik, Sobel, Schulz, & Glymour, 2001; Legare & Clegg, 2015; Sobel & Legare, 2014). In these studies, both variables exist in the same attentional frame, making it possible for the child to attend to and realize the relationship between them.

Other instances of action at a distance occur at an attentional distance, where the relationship between causes and effects is obscured by space or other variables that make it difficult to perceive their covariation. This led Grotzer and Solis (2015) to introduce the term, *action at an attentional distance* (A@AD) to underscore the distinction. In action at an attentional distance, causes and effects exist in different attentional frames. Given the importance of covariation for discerning the possibility and reliability of a causal connection, A@AD introduces considerable complexity to recognizing that particular causal relationships exist.

Covariation is not the only form of causal induction, however. Research has also investigated how learners of different ages reason from mechanism knowledge; by knowing how different mechanisms behave, it is possible to reason about potential outcomes even when it is not possible to discern a covariation relationship (e.g., Ahn, Kalish, Medin, & Gelman, 1995; Buchanan & Sobel, 2011). Other research has investigated how children use testimony from others to make decisions about how phenomena in the world work (Harris, 2012). Modes of causal induction are sometimes viewed as competing with one another, but often, when reasoning about real world complexities, like those that involve A@AD, individuals draw upon all available modes of causal induction that interact in various ways in support of each other to inform causal reasoning (Grotzer & Tutwiler, 2014).

Previous research has found that second through sixth graders typically generate local explanations across a variety of problem contexts when given interview scenarios that could have proximal or distal explanations (Grotzer & Solis, 2015). When students are able to generate distal explanations, this hinges upon having content-relevant mechanism knowledge that enables them to build the causal connection. This suggests that the concept of A@AD is within the repertoire of elementary students' causal explanations if they can imagine a mediating mechanism. How learners reason about contexts in which spatial and temporal factors separate causes and effects—making it difficult to discern covariation—is an important research question, particularly in the case of ecological science and environmental studies in which phenoma often occur across spatial and temporal gaps. Understanding how learners spontaneously reason in these cases can inform instructional design that scaffolds children's awareness that spatially and temporally local actions can have distal effects and vice versa.

A question in relation to previous research findings is whether students recognize A@AD as a type of causal pattern in the absence of mechanism knowledge. In extant findings, infants expressed surprise when observing action at a distance in which cause and effect were within one attentional frame (Spelke, Phillips, & Woodward, 1995). Older children presumably would have had opportunities to witness and test action at a distance concepts within the same attentional frames, such as turning on an overhead light, making magnets move on a table, or playing with their shadows at recess, so they may have generalized a pattern of action at a distance as a possibility that they may extend to action at an attentional distance phenomena. The present study investigated whether kindergartners expressed the belief that action at an attentional distance is possible, in both familiar and unfamiliar scenarios. It investigated the following questions:

1) Do young students accept action at an attentional distance as a causal explanation when the cause and its effect are not both perceptible in the same attentional set due to spatial distance or barriers?
2) Do young students generate responses that present action at an attentional distance as a possible causal explanation? If so, what are the features of events or phenomena that students accept as action at an attentional distance? If not, what are the features of events or phenomena that students reject as action at an attentional distance?
3) What are the reasoning patterns that enable students' ability and inclination to accept action at an attentional distance and produce responses that explain it?

A series of interview tasks that involved increasing levels of attentional distance in both familiar and unfamiliar contexts were developed to address the above research questions. Familiar and unfamiliar scenarios allowed a comparison between instances in which students likely had prior knowledge to refer to and instances they likely did not. Qualitative methods, described next, were employed to characterize students' causal explanations and reasoning patterns and identify the features of the phenomena that elicited (or not) A@AD responses.

2. Method

2.1 Participants

The sample consisted of 25 kindergarten students (13 female). Students attended a public charter school in an urban district of the Northeastern United States, where 95% students are students of color and 80% receive free or reduced lunch.

2.2 Tasks

It was important to understand how students' familiarity with phenomena influenced their ability to reason about a complex causal pattern such as A@AD. Prior to data collection, we conducted naturalistic classroom and playground observations to identify experiences related to A@AD phenomena that occur spontaneously in children's school environment. Understanding the nature of students' daily experiences informed the design of familiar scenarios and scenarios that incorporated unfamiliar components. Knowledge of students' daily experiences also allowed us to design scenarios that were developmentally appropriate for participants in this age range.

Students participated in two sessions in which they were presented with different scenarios and were asked to describe their understanding of the causality involved. Scenarios and the A@AD features tested in each scenario are described below and summarized in Table 1. Scenarios involved a protagonist who had informed the interviewer about a phenomenon. The interviewer then asked students to share their ideas about the veracity of the protagonists' claims. In the first session, the hypothetical protagonist was someone about the students' age (afirst grader) to increase the likelihood that children would feel comfortable disagreeing with the protagonist. In the second session, the protagonist was the researcher's coworker who, as the researcher explained, was "sometimes serious and sometimes joking," again providing students with an opportunity to disagree with the protagonist, if they deemed it necessary based on their causal reasoning. The choice of protagonists was informed by the extensive research that demonstrates that children take into account various informant characteristics when deciding whether or not to trust and accept their testimony (Harris, 2012). According to this research, children demonstrate selective trust in others' testimony based on informants' previous accuracy and group membership (Harris & Corriveau, 2011) but sometimes override testimony altogether to trust in their own perceptual judgments (Corriveau & Harris, 2010). By choosing a peer and an adult informant who was sometimes serious and sometimes joking, we sought to strike a balance between providing information from an apparently trustworthy source (the protagonist) and the possibility of disagreeing with this informant based on students' own causal judgments.

Table 1. Summary of Tasks in Session 1 and Session 2

Session 1	
Scenario Description	A@AD Features
Baseline: Student plays with magnets and is asked about the attraction and repulsion that occurs spontaneously between magnets as they play.	Action at a distance, but both cause and effect are familiar and within the same attentional space.
1) Student is told a first grader said that the voice coming through the loudspeaker in the classroom was coming from the office downstairs.	Action in two different attentional frames, at an attentional distance, but both of which are familiar to the students and within their awareness.
2) Student is told that a first grader in a school a few miles away said that s/he could make the researcher's cat purse "meow."	Action at an attentional distance with effect within attentional space and cause outside attentional space; unfamiliar context.
Session 2	
1) Student is told that the researcher's coworker said that she could control a camera in the room from far away.	Action at an attentional distance with effect within attentional space and cause outside attentional space; unfamiliar context.
2) Student is told that the researcher's coworker said that they could see and control a camera in Florida using a tablet.	Action at an attentional distance with cause within attentional space and effect outside attentional space; unfamiliar context.

2.2.1 Study Session 1 Tasks

In Session 1, students were presented with an initial action-at-a-distance task to ascertain that children understood that causes and effects can interact across a physical gap and two A@AD test scenarios. In the initial task, students were invited to play with an assortment of magnets and asked to react to instances of attraction and repulsion that occurred spontaneously as children played. Playing with magnets was a common activity in the kindergarten classroom; using them in this first activity allowed us to introduce students to the study context and probe their reaction to a familiar phenomenon that involved physical action at a distance (i.e., magnets attracting and repelling at a distance) but where the cause and effect occurred within the same attentional space. In this case, the task was familiar, and the cause and effect were both perceivable in the same space and at the same time. In line with prior research (e.g., Kushnir & Gopnik, 2007), the majority of students' responses to this magnet task (92%) indicated acceptance of the possibility of action at a distance. Only two students responded negatively to the action at a distance questions, but this did not appear to influence their responses to the subsequent A@AD scenarios. Thus, this task is not discussed further in the Results section.

The first A@AD task in Session 1 involved asking students whether it was possible for someone in the school office downstairs to say something that could be heard through a loudspeaker located in the classroom where students were being interviewed on the second floor. The interviewer asked, “I was here earlier this morning with a first grader at this school, and he told me that he can hear somebody from the office say something out of that box over there [researcher points to loudspeaker]. What do you think about that? Can we hear somebody from the office through that box?” The researcher followed with open-ended questions to allow students to explain their reasoning. Although cause and effect occurred in different attentional frames, this was a phenomenon that was familiar to students based on our naturalistic observations. In the second A@AD task, the researcher manipulated a cat-shaped purse (see Figure 1) to produce a meowing sound and asked students whether someone could be making the purse meow from blocks away. The researcher placed the cat purse on the interview table and surreptitiously deployed a sound box that made a meowing sound under the table directly below the purse. At specific moments in the interview, the researcher would deploy the sound box by pressing it against the bottom of the table. No child in the study saw the sound box or identified the actual source of the meowing. The researcher called the students’ attention to the sound, “Do you hear that? What does it sound like?” Then, the researcher went on to explain the following: “Remember that first grader I was telling you about? Well, he said that around this time, he would make my cat purse meow from his house that is a few miles away from here. What do you think about that? Can he make my cat purse meow all the way from his house?” The scenario was novel for students and involved an effect that was perceivable but introduced a potential cause that was beyond their attentional space.

Figure 1. Front and side view of cat-shaped purse used for the meowing purse scenario

2.2.2 Study Session 2 Tasks

In Session 2, students were presented with two unfamiliar A@AD scenarios. First, students observed a video camera in the room inexplicably turning on and off and zooming in and out—in fact, the camera was being manipulated by a second researcher using a remote control that was out of students’ sight. This second researcher would call the attention of the first researcher to the phenomenon, “[Researcher 1], it looks like this camera just turned on. The red light on the camera just came on like it is filming.” In addition, researchers showed students that the camera zoomed in and out and said, “The camera is zooming in and out, did you see that?” to further call their attention to the phenomenon. Students were asked whether someone could be operating the camera from far away. The researcher conducting the interview would turn to the student and explain, “That’s interesting. Someone else who works with me said that she had to leave the school but that she would work the camera from wherever she went. Sometimes she is joking and sometimes she really means it. What do you think about that? Can somebody make the camera work from far away?” This scenario involved a perceivable effect and a suggested cause that was beyond students’ attentional space.

In the second scenario in Session 2, students were shown a webpage on a tablet and were told that the researcher’s coworker had said that they could see the live image of a beach in Florida on the tablet. Students were asked whether it was possible for them to view scenes on the screen from a camera recording on a beach all the way in Florida. “My coworker told me that we can see a beach far away in Florida on this screen. Sometimes she’s joking and sometimes she’s serious. Do you think we can see a beach far away in Florida on this screen?” Then, students were asked whether they believed they could control the camera in Florida by using the tablet on the table. “My coworker also told me we can make the camera move on the beach in Florida from this screen here. Sometimes she’s joking and sometimes she’s serious. Do you think we can make the camera move far away in Florida?” Lastly, they were given the opportunity to manipulate the tablet and observe how the beach scenes changed as they pressed on the navigation tools and asked whether they believed they could move the camera on the beach in Florida after manipulating the tablet. In this case, students were presented with a scenario where the suggested cause was local (i.e., the manipulating the tablet) and the potential effect was far away (i.e., a camera moving far away). In addition, students were asked to make a judgment before and after being allowed to intervene in the scenario. Intervening upon the tablet offered temporal covariation information that helped us investigate whether temporal covariation evidence could override spatial gaps when students reasoned about the phenomenon, as has been reported in prior research (Kushnir & Gopnik, 2007). Research has demonstrated that intervening rather than simply observing another person manipulating an object has implications for children’s learning about causal structures (Sobel & Sommerville, 2010), and we wanted to investigate whether this was also the case with phenomena involving attentional gaps that obscured covariation information.

Some of the unfamiliar tasks involved a degree of experimenter manipulation to create the appearance of the A@AD phenomenon, not unlike other studies in developmental science (e.g., blicket detector used in studies of causal reasoning, e.g., Gopnik et al., 2004; Griffiths, Sobel, Tenenbaum, & Gopnik, 2011). The focus was not on whether children accurately described or discovered the actual causal structure involved but how they responded to the evidence presented to them and how this informed their reasoning about action at an attentional distance.

2.3 Procedures

Study sessions were conducted in a quiet resource room at the school. One researcher interviewed students and a second researcher took notes of student responses as well as helped with presentation of scenarios. The interviewer began each session with a brief play session using objects (e.g., magnets in Session 1 or finger puppets in Session 2) to create rapport with students. Once students showed signs of feeling at ease with the researcher and the study context, the interviewer moved on to presenting students with the study scenarios. Once presented with a particular scenario, students were first asked possibility questions (“Is it possible?”) and then open-ended questions to elaborate their reasoning (e.g., “What do you think about that?” “What makes you say that?” “Tell me more about what you’re thinking.”). Between scenarios, the interviewer continued playing with the child using the magnets or puppets for a few minutes, until it seemed appropriate to introduce the next scenario. Scenarios within each session were counterbalanced between students. Sessions were 15-30 minutes long and were video- and audio-recorded for transcription and data analysis purposes.

2.4 Data Sources & Analysis

Data sources consisted of audiotapes, videotapes, and transcriptions of the study sessions. Initial emic, open coding was employed to identify themes in students’ responses (Charmaz, 2002, 2006; Strauss & Corbin, 1990). Two researchers independently watched session videos and documented insights regarding students’ responses to study scenarios. Memos were developed for individual students documenting their reasoning in narratives that summarized response patterns within and across different tasks. Researchers looked for students’ possibility judgments and causal explanations as well as other emergent response patterns that helped explain children’s reasoning, as discussed below. As patterns emerged across memos, the researchers noted them in a list of recurring themes (or categories) of responses. Confirming and disconfirming evidence for each reasoning pattern that was identified from students’ responses was incorporated into the narratives. Categories were discussed and elaborated, and discrepancies in interpretation of the data were resolved. These categories were then incorporated into a coding protocol utilized to score session transcripts and generate descriptive statistics that helped characterize the nature of students’ responses.

Codes were divided into four categories. Categories were not mutually exclusive categories; therefore, multiple codes could be applied to the same segment of interview transcripts. *Possibility judgment codes* referred to students’ responses to the possibility questions—that is, whether or not it was possible for the cause and effect to be separated by space in the scenario. They included “accepts” which indicated that the student accepted the A@AD presented in the scenario (i.e., that a cause and effect could be far away from each other) and “rejects” which indicated that students rejected the possibility. *Causal explanation codes* indicated whether students’ explanations of the scenarios reflected a local, distant, A@AD, or an ambiguous understanding of the phenomenon being presented. (Note 1)

We defined "local" as referring to responses that indicated students' belief that both the cause and effect had to reside within the same attentional space; that is, where the covariation between cause and effect was perceptible to the student or protagonist in the scenario. Any responses that referred to "here" or "the room" or indicated that a causal relationship was not possible across a distance beyond the room were considered local. "Distant" referred to responses where the cause or effect identified by the student was located outside the local space but around the school in locations that were accessible and likely familiar to students. For example, students might locate the cause down the hall, downstairs, or in the playground, and all these responses would be considered distant. In this case, students demonstrated that although the cause or effect did not reside within the immediate attentional frame enabling them to discern temporally contiguous covariation, the relationship existed within their attentional repertoire based on previous knowledge or experience. "A@AD" responses indicated explanations where students referenced causes located blocks or miles away indicating that they were thinking outside the familiar space of the school. If students used the term "far away" or "a long way from here," these were considered A@AD responses because they indicated students believed the cause was beyond the school. According to these responses, the cause or effect was located at an attentional distance and beyond students' attentional repertoire. Finally, "ambiguous" referred to instances when students expressed a causal explanation of the scenario but did not discuss the cause and effect relationship as either local, distant, or A@AD. This code was rarely used but it helped us identify instances when students were thinking about the causality in the scenario in ways that did not directly answer our research questions.

Mechanism codes surfaced as an emergent pattern and referred to the ways in which students incorporated mechanism information in their explanations to make sense of the scenarios. These codes aligned with previous research that has demonstrated that children consider possible mechanisms as part of their causal reasoning (e.g., Keil, 1994; Sobel & Buchanan, 2009; Buchanan & Sobel, 2011). We identified three ways in which students spoke about mechanisms in their responses: intra-scenario explanations, extra-scenario explanations, and magical explanations. In "intra-scenario" responses, students described their ideas about the mechanisms of objects presented in the scenarios. The important feature in this category was that students focused on the objects provided in the scenario and either used their prior knowledge or contextual information to make sense of the possible mechanisms at work, whether technically accurate or not. Examples of responses in this category included students describing how the sound gets from someone speaking in the office to the loudspeaker upstairs and students describing that tablets work using the Internet to connect to computers around the world. "Extra-scenario explanations" referred to instances when students introduced objects not presented in the scenario as they reasoned about the mechanism(s) involved in the scenario. They typically described devices not mentioned in the original scenario, such as machines, remotes, or cell phones that added mechanism information to help explain the A@AD phenomenon. The important feature in this case was that, instead of being limited to the objects presented to them, they incorporate new object information that helped explain the scenario. Again, responses included in this category did not have to be technically accurate. "Magical explanations" referred to instances when children used fantastical responses in place of material explanations. Responses that referred to magicians or magical powers, ghosts, or invisible beings were all considered magical explanations. This code coincided with previous research that demonstrates that young children accept and retain magical explanations for anomalous events even after the mechanism of the phenomenon is explained to them (e.g., Subbotsky, 2004). The important feature in this type of response was that students provided alternatives to physical mechanisms.

Cognitive strategy codes referred to reasoning strategies that students employed to think through scenarios. These codes included "perception and awareness," in which students identified and described features of the scenarios that were important to figuring out the cause-effect relationship (e.g., noticing that certain icons on the tablet screen flashed when it was the user's turn to control the webcam); "seeks evidence," instances when students explored or described the kind of evidence that would provide clues as to the causal relationship involved in the scenario (e.g., touching or listening closely to the cat purse to figure out where the sound is coming from); "co-variation," in which students described the relationship between an action or event and the consequences of that action or event in the scenario (e.g., noticing a relationship between a clicking sound and a voice coming out of the loudspeaker); "intervention," in which students described a relationship between their own actions and the outcome being observed or presented in the scenario (e.g., noticing a relationship between their actions on the tablet screen and the movement of the images on the screen); "prior knowledge," in which students reacted to the scenarios in a way that suggested they were familiar with what was being described and explained this prior knowledge or experience (e.g., describing how the buses are called out through the loudspeaker every afternoon); and "transfer," in which students referenced details of an earlier scenario in trying to reason about or explain a new scenario that was presented to them.

A primary coder scored 100% of interview transcripts, deciding on instances to be coded. A second coder scored 25% of all instances to establish inter-rater reliability. Reliability across transcripts ranged from 81% - 97% (κ = .80 - .97). Disagreements were discussed and resolved, and the entire data set was revised to ensure that it reflected final agreements on code descriptions and decision rules.

3. Results

Below, we characterize students' responses to the different A@AD scenarios to illustrate how the familiarity of a phenomenon, possible mechanisms, and students' reasoning strategies affected their ability and inclination to accept and explain action at an attentional distance.

3.1 Students Revealed the Ability to Accept and Explain A@AD

When looking at the overall counts of instances coded, students accepted the possibility of A@AD in 53% of their possibility judgment responses, compared to 47% of instances when they rejected the possibility (see Table 2). When looking at individual students, we similarly observed that students accepted (M = 54%, SD = .20; Min = 13%, Max = 91%) slightly more than rejected (M = 46%, SD = .20; Min = 9%, Max = 88%) A@AD. Figure 2 shows that 14 students accepted A@AD 50% or more of the time.

Table 2. Frequencies (percentages) of Student Responses Organized by Possibility Judgment, Causal Explanation, Mechanism, and Cognitive Strategies Categories across Sessions 1 and 2

Code Categories	**Session 1** (***n=328)***	**Session 2** (***n=437)***	**Total**
Possibility Judgment			
Accepts	73 (60.83%)	110 (49.11%)	183 (53.2%)
Rejects	47 (39.17%)	114 (50.89%)	161 (46.8%)
Total	120 (100%)	224 (100%)	344 (100%)
Causal Explanation			
Local	55 (59.14%)	36 (50.70%)	91 (55.49%)
Distant	27 (29.03%)	4 (5.63%)	31 (18.9%)
A@AD	5 (5.38%)	26 (36.62%)	31 (18.9%)
Ambiguous	6 (6.45%)	5 (7.04%)	11 (6.71%)
Total	93 (100%)	71 (100%)	164 (100%)
Mechanism			
Extra-Scenario Explanations	20 (66.67%)	24 (50%)	44 (56.41%)
Intra-Scenario Explanations	6 (20%)	17 (35.42%)	23 (29.49%)
Magical Explanations	4 (13.33%)	7 (14.58%)	11 (14.10%)
Total	30 (100%)	48 (100%)	78 (100%)
Cognitive Strategies			
Seeks Evidence	40 (47.06%)	21 (22.34%)	61 (34.08%)
Prior Knowledge	32 (37.65%)	7 (7.45%)	39 (21.79%)
Perception/Awareness	3 (3.53%)	32 (34.04%)	35 (19.55%)
Intervention	8 (9.41%)	15 (15.96%)	23 (12.85%)
Covariation	2 (2.35%)	10 (10.64%)	12 (6.70%)
Transfer	0 (0%)	9 (9.57%)	9 (5.03%)
Total	85 (100%)	94 (100%)	179 (100%)

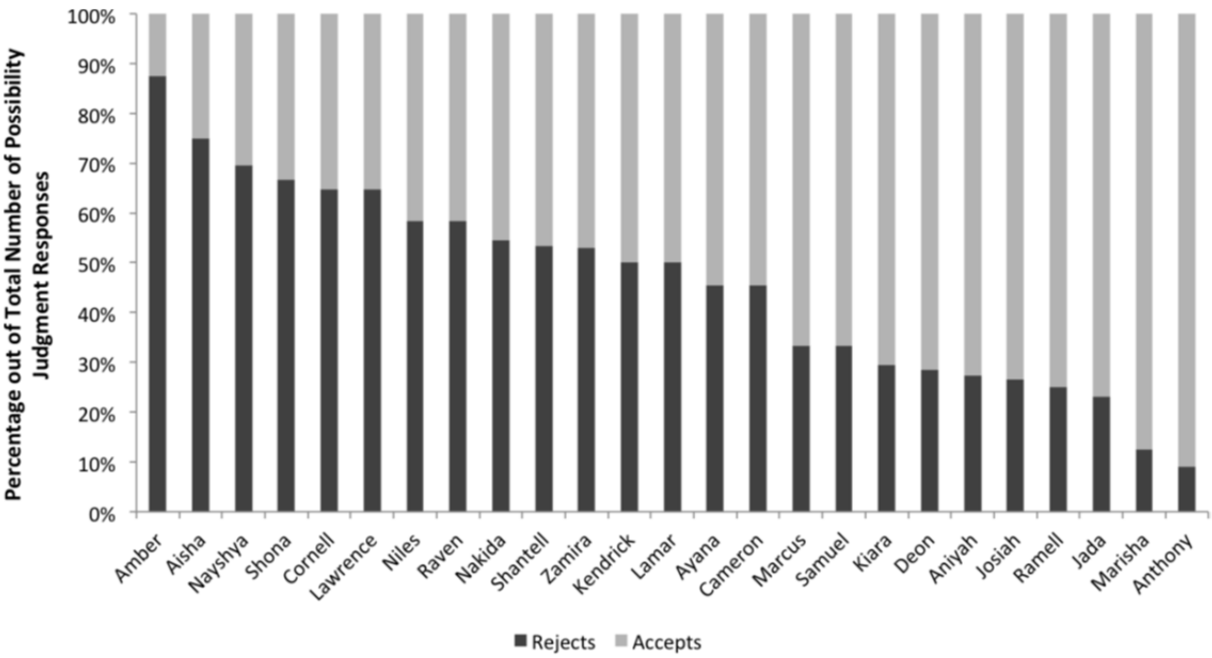

Figure 2. Percentage of Accepts and Rejects Responses Given by Individual Students

When asked to explain their reasoning, 22 students provided explanations (*M* = 6.95, *SD* = 1.00; Min = 2, Max = 21). Across these 22 students who provided explanations, 55% of students' explanations involved local reasoning, compared to 19% of students' responses that referred to distant explanations, and 19% that referred to A@AD. When looking at individual students, we observed that students provided more local explanations (*M* = 57%, *SD* = .29; Min = 0%, Max = 100%) than distant (M = 18%, SD = .19; Min = 0%, Max = 57%) or A@AD explanations (M = 26%, SD = .30). As shown in Figure 3, 13 students provided local explanations 50% of the time or more. For example, when asked whether someone could control a camera in the room from far away, Aisha responded, "She can only come here and do it," indicating that the protagonist could only do so by being in the room to control it. Similarly, when asked about using a tablet to control a camera in Florida, Shantell expressed local reasoning by explaining that the only way one could control a camera in Florida was by traveling to Florida to control the camera. (Note 2)

S: I'm thinking that when the camera's in Florida and we're still [at the school] and Florida is, and Florida is really far away we must get an airplane so we can move the camera.

I: We need an airplane to move the camera? Like the airplane can move the camera? Or we have to get on the airplane and go to Florida to move the camera?

S: We have to get on the plane to move the camera.

On the other hand, although many students provided local explanations, some were also able to provide responses that involved distances between causes and effects. Figure 3 shows that 12 students provided 50% or more responses that involved distance between cause and effect that went beyond their immediate attentional space. Samuel, for example, was able to utilize his knowledge of the Internet to explain how someone could use a tablet to control a camera in Florida.

S: You could type camera of Florida and then you could look in a camera in Florida. You could look in a camera in Florida!

I: Okay. When you say we can type, you can type, what do you mean by that? What do you mean by type? Like where are you typing that?

S: A camera just in Florida. And could check out a camera, so it's true.

I: Okay. I'm still wondering what you mean by type. Where are you typing that? S: Into the…[points to search bar].

I: Oh!! Into the [search] bar?

S: Yeah.

I: Okay. So you're telling me that you can search for it on the bar, you just type up camera in Florida and you can find it on a website like this?

S: Yeah

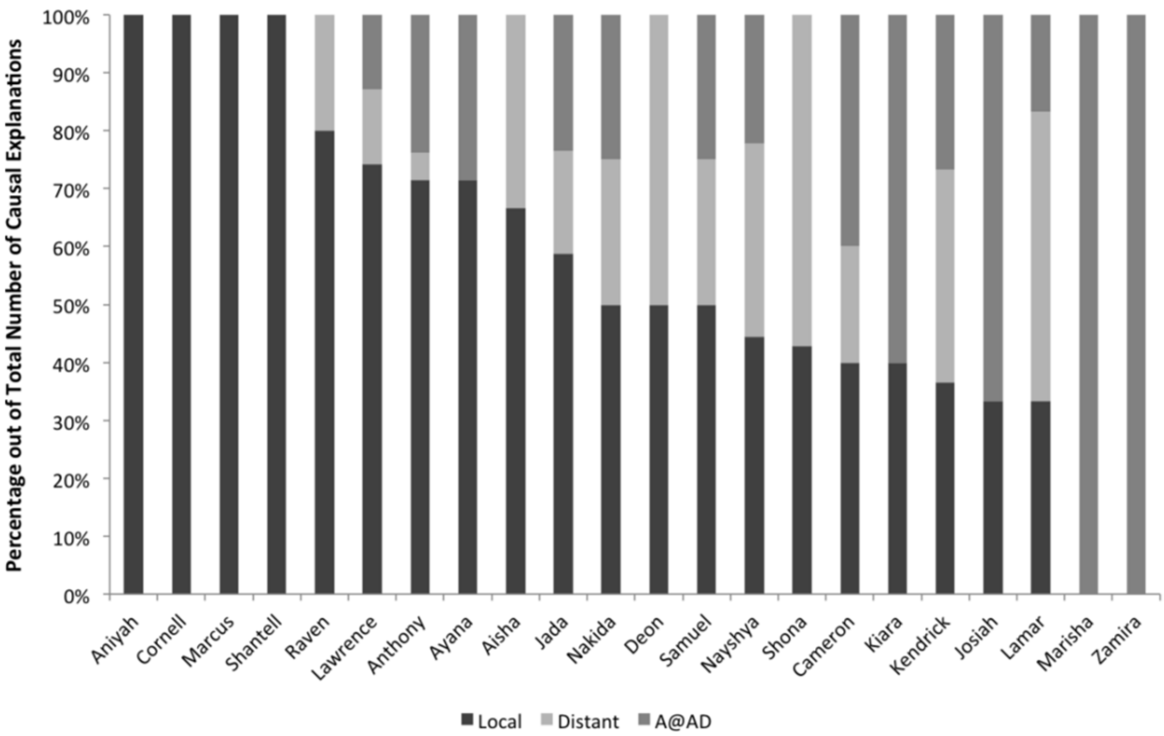

Figure 3. Percentage of Local, Distant, and A@AD Responses Given by Individual Students

Importantly, students' possibility judgments were not always consistent with their causal explanations, a more cognitively demanding task. By comparing Figures 2 and 3, we can see that students who rejected the possibility of A@AD at times provided A@AD explanations, and that students who accepted the possibility of A@AD at times provided local explanations. For example, Shona rejected A@AD in 67% of possibility judgment instances but provided A@AD responses in 57% of her causal explanations. Conversely, Aniyah accepted A@AD in 73% of instances but all her causal explanations were local. Figure 3 also shows that four students (i.e., Aniyah, Cornell, Marcus, and Shantell) provided 100% local responses, and two students (i.e., Marisha and Zamira) provided 100% A@AD responses. These students tended to give few explanations (1-3), which likely limited the variability in their responses. It is noteworthy, however, that for students whose responses were 100% local, all had at least one local response in the meowing purse scenario but only two of the students offered any responses in the tablet scenario. As discussed below, there appeared to be a relationship between the scenario, its causal features, and the kinds of responses it elicited.

3.2 Students Accepted and Explained Distance Between Causes and Effects in Familiar Scenarios

Analyzing student responses by scenario revealed clear patterns in the types of explanations that emerged. Figure 4 shows that student responses were mostly distant in the loudspeaker scenario; local in the meowing purse and camera scenario; and A@AD in the tablet scenario.

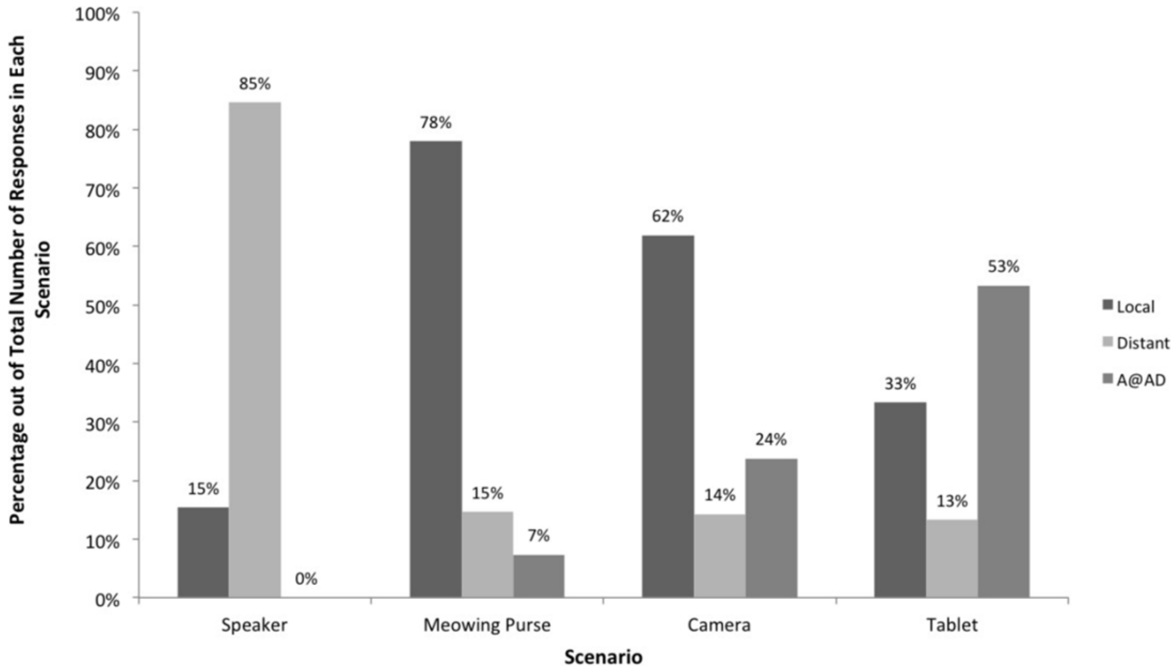

Figure 4. Percentage of Local, Distant, and A@AD Responses Given in Each Scenario

The loudspeaker scenario gave us an opportunity to observe how students responded to an event that occurred often in their context and was likely familiar to them. Most students were familiar with a voice coming out of the loudspeaker and had no problem accepting that a person in the office (or another building, as some of them suggested) could say something that would come out of the speaker. Twenty-one out of 25 students accepted the possibility of this event and provided detailed explanations of this familiar event. In fact, many of them used their personal experience and referred to the school secretary or principal making announcements through the loudspeaker, such as announcing the arrival of buses. Josiah explained, "When it's the end of the day they, they call buses and then they say, 'Please have all the students have their coats on for dismissal. Thank you.'" Zamira matter-of-factly stated,

Z: It calls the buses so we can go home.

I: Oh, it calls the buses? Did you hear it before?

Z: I heard it everyday.

And Samuel gave a detailed account of the phenomenon he was being asked to explain.

S: Ms. G!

I: Tell me more.

S: Ms. G can speak up there and she, the principal she puts on music so we could dance, and it comes out of that thingy.

I: And where's Ms. G?

S: Ms. G? She's in the, in the, she's in the office and she could make it all the way up there. You see that door where it comes out?

I: Uhuh, I did see that door.

S: Well we come in and in the front of the thing we could, you see Ms. G with the glasses, right?

I: Yeah, yeah.

S: That her! And she's, and there's this microphone that she speak out so it could come through that thing.

I: Oh, it comes through that box?

S: Yeah, that thingy thing.

Samuel not only accepted that this was possible but identified the cause as coming from the office downstairs and described the mechanism he had observed ("this microphone that she speak out so it could come through that thing"). This was not unlike the responses of other students who described their prior experiences with this phenomenon in detail and clearly placed the cause and effect at a distance but within the school space.

In this scenario, students had no problem accepting and describing a cause and effect being separated in space when the cause and effect were within their attentional and experiential repertoire. They had prior knowledge and direct evidence not only of the perceived effect but also of the potential cause. The cause that was identified in the scenario (someone speaking through the PA system in the office) occurred at a distance but not outside students' experience, which provided sufficient information for them to accept the possibility of action at a distance and explain the reasoning behind their causal judgment. Results from unfamiliar scenarios in which students had little or no prior experience or direct perceptual access demonstrated that students had a harder time accepting A@AD and explaining novel A@AD phenomena.

3.3 Students Rejected Distance Between Causes and Effects in Unfamiliar Scenarios

Unfamiliar scenarios presented an effect and a possible cause that was far beyond students' direct perception or day-to-day experience. Although some of the scenarios involved technology that can be native to many young children, the potential mechanisms were obscure enough to allow us to assess students' reactions to novel scenarios. For example, the meowing purse scenario was surprising for students and many seemed incredulous about the prospect of someone making a purse "meow" from a distance. Fourteen students initially rejected the possibility of someone making the purse meow from far away. Lawrence made sure he understood the scenario by asking a clarifying question and then clearly stated that he did not believe it was possible for someone to make the purse meow from far away.

L: He was in the [school] before?

I: No! He was in another school! And he told me that right around this time, he was going to make my cat purse meow!

L: I don't think that's true.

Even when they accepted the possibility, when pushed to explain the meowing purse phenomenon, the students considered various responses but tended not to come up with A@AD explanations; instead, they reasoned in ways that brought the cause closer to the effect or at least made the possible mechanism more familiar. They looked for a local mechanism in the purse (e.g., "I think it's something inside your bag.") or looked for potential causes at a distance but within their attentional repertoire (e.g., the classroom next door or somewhere right outside the school). Students' responses demonstrated that they doubted the possibility of the cause acting from far away, and rather devised alternative explanations. For example, Aisha did not believe that a first grader could make the purse meow from far away "because that would be crazy." She believed that someone had brought a cat to school, providing a cause that was within the school context, which was a familiar environment to her, even though she had never really seen a cat at school before. Jada believed the cause of the meowing sound was inside the purse and explored it, looking for the mechanism that was making the sound. When she did not find the connection between a potential cause and the sound, she declared that something was "wrong with it": I thinks going on is [unzips the purse and is looking inside it again]…not meowing anymore…something's wrong with it. [Student J zips up the purse.]"

Similarly, when asked whether someone far away could operate a camera in the room, 18 students were surprised and rejected the possibility initially. For example, Shantell explained, "When she goes everywhere and the camera is at [the school], she can't work it in for everywhere where she goes." Kendrick also rejected the idea, "I think she was joking. 'Cause she can't work the camera when she's all the way somewhere far, she just had to come there, that's all."

Students responded to the tablet scenario in a similar way to how they reacted in the meowing purse and camera scenarios. Initially they were skeptical, and 11 students did not believe they could see images through a camera in Florida with a tablet or operate a webcam from far away using a tablet. Nayshya explained that she did not believe she could control a camera in Florida "because you're far away from Florida, and Florida is far away from us." Interestingly, while initially only 6 students believed that they could see Florida via a camera displayed on the tablet screen, 13 students accepted that if they could indeed see a camera in Florida, it would be possible for them to control it using the tablet.

Despite students' initial skeptical responses to unfamiliar scenarios, some students accepted and elaborated A@AD explanations either when initially presented with the information or after exploring the scenario further.

After initially rejecting the notion of the meowing sound being controlled from far away and providing local alternative explanations, Nayshya suggested a mechanism that would explain a causal relationship at a distance.

N: Oh, I know!

I: What?

N: If he lives far far away maybe he has a key that makes your purse say that.

I: What kind of key?

N: Um, a magic key. That you can't see.

I: Oh really? So, if he has a magic key, he can make my cat purse meow?

N: Yeah!

Similarly, although Ayana initially rejected the notion that she could be controlling a webcam in Florida, after seeing the evidence from her own manipulation of the tablet, she had no doubt it was possible.

A: If we're controlling the camera around whole place, that means we can see everything that, that... [mumbles] controlling the camera.

I: What makes you think we're controlling the camera? Can you tell me more about that?

A: That we're pushing this to see everything. [A is holding the tablet.]

Students' ability to intervene in the tablet scenario informed students' reasoning toward A@AD; this is discussed further below.

3.4 Students Referred to Mechanisms in Their Reasoning

Students' responses demonstrated both their initial ideas as well as their careful thinking through of the information and evidence that was presented to them. They considered multiple potential explanations, and as they did, they expressed ideas about mechanisms. Prior experience or knowledge of different mechanisms had powerful explanatory power, and at times, it was exactly this mechanism reasoning that allowed students to construct a causal explanation that involved A@AD. Students' use of mechanisms involved either knowledge about the objects presented to them in the scenario, outside information or devices that were not presented as part of the scenario, or fantastical explanations. Importantly, the mechanisms students described were not necessarily technically or scientifically accurate, but they demonstrated their attention to how the cause and effect relationship could function in the scenario.

3.4.1 Intra-Scenario Explanations

In 30% of the instances when students discussed mechanisms, they referred to knowledge they had or gathered about the objects involved in the scenarios. Whether reasoning about the loudspeaker, cat purse, camera, or tablet, children seemed to use any prior knowledge they had about how these objects worked or the details included in the scenario to come up with an explanation of the phenomenon. For example, Niles described his ideas about the mechanism involved in the sound coming from the loudspeaker.

N: That's called a speaker. I: What does it do?

N: When you press the button that says, that says press to call it, it says, it says something.

Lawrence accepted the possibility of A@AD in the table scenario and described what he knew about how the webcam application worked.

I: Do you think that it's really you moving it? Moving the camera? Or not?

L: Mmm…It's me really moving the camera.

I: And what makes you think that?

L: Because all you have to do is put these little blue things somewhere, and then it will go somewhere else.

As illustrated by these two excerpts, some students had prior knowledge of the objects in the scenarios—Niles had seen the PA system operated at the school—but others derived information about the objects as they interacted with them throughout the interview—Lawrence gleaned information about how the webcam worked after using the tablet.

3.4.2 Extra-Scenario Explanations

In 54% of instances, students introduced ideas about mechanisms involved in devices not mentioned in the scenario. By incorporating knowledge about devices, students were able to expand the possible explanations for the A@AD scenarios. When responding to the meowing purse scenario, Anthony described a device ("a thing…painted…and has little scraped holes") that could produce the sound from the wall. Although in this example it is not clear that Anthony's explanation involves A@AD, he is able to imagine a device to formulate an explanation for the meowing sound.

A: When you can't see something and you can hear something, it's just a thing where, where you cannot see, and it's painted, and has little scraped holes, like I said you can't see it, and it can hear far away.

I: Can you tell me more about this thing that can hear far away?

A: Hum. That it, it's [picks up the cat purse, turns in upside down, explores the outside of it] controlling all the way to here [at "here" A points up to the same spot on the wall].

Some students discussed a remote-control mechanism. Aisha considered the possibility that the camera in the room could be operated from far away using "a remote controller" (although later she concluded that controlling a camera from far away was not possible, even with a remote control). Zamira had a similar explanation,

I: So, do you think my friend is doing that?

Z: Yes.

I: Yeah?

Z: I guess she has a remote that's doing that?

I: Tell me more about that. A remote? What do you mean?

Z: Like when she has a remote and she's all the way to, to another street and she has this remote and she's doing something to like a, a camera.

Other students mentioned keys, microphones, and radios, as illustrated in some of the excerpts above. Some of these devices made sense within the premise of the scenarios and others did not; however, in either case, these devices allowed students to expand the repertoire of potential mechanisms that would help explain the A@AD phenomena.

3.4.3 Magical Explanations

Interestingly, some students used magic and other fantastical explanations as potential mechanisms to explain unfamiliar scenarios. In 14% of instances, children referred to magic (and sometimes specifically a wand) or other supernatural mechanisms like ghosts to explain the novel scenarios. When asked about the meowing purse, Lawrence answered,

L: Um, I'm not sure 'cause only a magician could do that.

I: Oh, a magician. Tell me about that. About a magician doing it.

L: A magician is people who is so magic…but some magicians don't have a wand, they just use their hands as one.

Kendrick also suggested that a wand could make the cat purse meow from far away.

K: I think he has a wand to make that.

I: He what?

K: I think he has a wizard wand I: A wizard wand?

K: Yeah. To make that.

When explaining the camera that turned on and off, Raven suggested that, "It's haunted up here," and that, "There's ghost-es…Ghost-es are under the table. Probably they're in the closet." She even suggested an invisible person near the camera was turning it on.

Often when students were engaged in thinking about explanations for the scenario and considering the possibility of A@AD they offered ideas about potential mechanisms. Whether students mentioned their past experience of mechanisms, provided specific ideas of devices that could make A@AD possible, or invoked magic as an explanation, these efforts provided a glimpse into the wealth of cognitive strategies that students employed in reasoning about possible mechanisms in familiar and unfamiliar instances of causality.

3.5 Students Employed Various Cognitive Strategies to Reason About Scenarios

Responses to unfamiliar scenarios demonstrated students' difficulty accepting and explaining causal phenomena where the cause and its effect are not both perceptible in the same attentional space. However, students actively reasoned about the phenomena in these scenarios. As interviews progressed and as students continued to explore the scenarios, students proposed various hypotheses and explored their plausibility as they tried to explain the phenomenon they were observing. In doing this, they seemed to be trying to connect the repertoire of causes and mechanisms they were familiar with to the effects that they were being asked to explain. In order to do this, students intuitively employed a number of cognitive strategies.

In previous sections, we have discussed students' use of prior knowledge to inform their reasoning about scenarios. In other instances, students transferred their understanding from one scenario to another, which seemed to inform their thinking about A@AD. Josiah, for example, noted, "The tablet and the camera's kinda like the same because you can see some - cause on the tablet you can see something far away and, and on the, the camera can see something far away." Although transfer only occurred in about 5% of all the instances coded, all the instances occurred in Session 2, suggesting that students had the opportunity to compare cases with contrasting surface features but similar deep structure features across and within sessions to abstract a causal schema that revealed the deep structure shared by all the cases, an ability for analogical transfer also documented by Gick and Holyoak (1980, 1983) (also see, Gentner, & Francisco Maravilla, 2018).

Four cognitive strategies seemed particularly prominent across students and scenarios or appeared most relevant to understanding students' reasoning about action at an attentional distance: seeking additional evidence; perception/awareness of important causal features in the scenario; noticing co-variation between causes and effects in scenarios; exploring the relationship between their interventions and outcomes. Here we discuss these four reasoning strategies in detail, but frequencies for all codes in this category are included in Table 2.

3.5.1 Seeking Evidence

Students carefully observed the demonstrations in scenarios and when these demonstrations did not provide sufficient information to point to critical variables, in 34% of instances, students sought their own evidence. They often looked around them (standing up and looking around, going to the window to see if there was anything going on outside, listening to the classroom next door), looking for clues and evidence that would help them explain the phenomena. Although in some instances students' exploration of the available data confirmed local judgments, in other cases their observations and the evidence they produced by their own interventions supported their reasoning about action at an attentional distance.

In the meowing purse scenario, several students had a notion that the mechanism producing the sound was inside the purse. They examined the purse carefully and provided local explanations to accompany this exploration.

Anthony explored the purse and thought that maybe "wiggling" it was what made the sound happen: "Yeah. Maybe it's coming from here [A touches the front of the purse]. Or maybe here [A touches the back of the purse]. Oh. It just makes a noise. Oh, I see why it's making the noise, 'cause if we wiggle it [A picks up the purse and shakes it, then puts it down], so much, it's gonna come."

Jada had a similar reaction to the meowing purse scenario and also looked in the bag for the cause.

I: Where do you think it's coming from?

J: Right here.

I: Ohhh. You mean, like, right at the very bottom? [Student J opens up the purse to I and shows her the very bottom, rear corner of the bag.]

J: When it meows, I'm going to hear it. [She holds the cat purse to her ear to demonstrate.]

In the camera scenario, Anthony showed an interest in testing whether his actions had any effect on the movements of the camera in front of him.

A: Maybe if we do this [A waves his hand up and down in front of the camera. He does this for a little while, testing] to that hole, it maybe do something.

I: It can - like what kind of thing?

A: Like it can make it go closer again.

I: Oh, it can zoom in?

A: Uh-huh.

I: So if we move our hands, then maybe it can zoom in?

A: Uh-huh.

3.5.2 Perception/Awareness

In 20% of the cognitive strategies coded, students demonstrated they were perceptive and aware of scenario details that could serve as clues to the causality involved. These scenario details or features referred to information inherent in the scenario that could provide students with insights into the causal structure. For example, students noticed the meowing sound and connected it to the cat purse sitting on the table. They identified the speaker box on the wall and understood the idea that a voice came through there. Even when unprompted, they noticed when a camera zoomed in and out or video images on the tablet moved. They realized that the different icons on the tablet screen helped to manipulate the webpage. Describing these features was not in itself a causal explanation, but their awareness of these important features worked as an entry point for students to develop alternative hypotheses about what was going on in scenarios. Cameron paid close attention to the evidence in the tablet scenario, which later helped him to develop an A@AD explanation of why it was possible for him to control a camera all the way in Florida using the camera.

C: Um like, here we like, here we [are] like changing the color, from right there and, and you turn in into, now it's yellow…

R: Uhuh

C: …and that is like, the first time, we didn't see the color…

R: Mmhm

C: …but now, now you clicked on it and it, it's like green.

Cameron seemed to be picking up on the relationship between tapping the rectangle, which is how individuals indicate that they want to control the camera, and the color of the rectangle changing, which is what happens when individuals gain/lose control of the camera. As he gained a better understanding of the different factors, he also seemed to create a more complex understanding of the causal structure. On this same scenario, Zamira also picked up on salient features of the causal relationship and verbalized these features when describing their thinking.

Z: It's going to umm, other places. [Z continues touching tablet screen]

I: What's going to other places?

Z: When we press, um this, it goes to um, it goes to this.

As students noted important features of scenarios, they formulated ideas about the causal structure and began to explore possible explanations for the cause-effect relationship involved. As discussed next, sometimes this involved proposing or seeking possible evidence to confirm or disconfirm their causal hypotheses.

3.5.3 Covariation

In 7% of instances students provided explanations that suggested a relationship or covariation between potential causes and effects in scenarios, either by referring to evidence they observed in scenarios or using their previous knowledge of the objects or events presented. In some cases, suggesting a cause-effect relationship demonstrated students' awareness of important details or features that resulted from evidence that emerged in the scenarios themselves. For example, Aniyah realized that when working on the tablet, "you have to press the box and then it will move." Lawrence was able include information about covariation in his description of how the tablet was able to control the camera in Florida, "Because all you have to do is put these little blue things somewhere, and then it will go somewhere else." In the tablet scenario, even though the camera that was being operated from far away was distant and beyond the immediate attentional space, manipulating the tablet worked as a mediating source of information allowing students to discern a covariation relationship. This is discussed further in the next section.

The covariation relationships students discussed were not always perceivable to them during the interview; however, in some cases, they were able to conjure up candidate causes or effects and the relationship between them based on their existing causal repertoire. In an example described previously, Niles was able to use his prior knowledge of the speaker mechanism—he may have been referring to a memory of seeing a person speak into the microphone while he was near the office, or recognized the speaker's voice and inferred a relationship, or remembered the testimony of someone who told him the speaker worked in that way—to describe how he could hear a loudspeaker announcement in his classroom. His explanation included information about covariation, “When you press the button that says, that says press to call it, it says something.”

In the examples described, students were noticing and describing the relationship between potential events or interventions and their corresponding effects, which helped them to reason about the scenarios. Nevertheless, students referred to covariation rarely (only 7% of responses) and this is likely because, as discussed in the introduction, covariation is obscured in A@AD cases making it hard to discern a causal relationship. Similar to their awareness of important features or seeking evidence, when they generated ideas about covariation, this seemed to help some students, like Lawrence and Niles, move from a local to distant or A@AD understanding of the scenarios.

3.5.5 Intervention

Anthony’s reaction to the camera scenario, above, illustrates not only students’ tendency to seek evidence or pay attention to covariation but also some students’ attention to the effect of their interventions. In certain instances, students sought evidence by intervening in the scenario. They looked for the effects of their actions and used this information to draw conclusions about the causality involved in the scenario. Although students used interventions to test causal hypotheses in only 13% of instances, this strategy illustrates students’ efforts to seek additional evidence to determine the causality in scenarios and it aligns with existing literature on children’s reasoning from their own causal interventions (e.g., Schulz, Gopnik, & Glymour, 2007; Sobel & Sommerville, 2010). Intervention enabled children to witness the temporal covariation of their actions and the movements on the tablet screen and utilize this information in considering the spatial gap being presented to them in the scenario. As with other categories, sometimes the interventions students employed tested local hypotheses. For example, when asked about a camera being operated from far away, Nakida rejected the possibility that someone from far away could be operating it and suggested that her own actions were actually manipulating the zooming in and out of the camera in the room.

I: Can she work the camera from outside the school?

N: No

I: What do you think about that?

N: No, you cannot do that.

…

N: It’s weird because when I do this it goes up and when I go back it goes back. I: Oh, so you think when you move then the camera zooms in and out?

N: Kind of big. When it gets farther it does that and when it goes back. [Leaning back and forward in her chair.]

I: Huh. So, you think you can make the camera do that when you move?

N: Yep

In this case, Nakida accepted the possibility of a cause (i.e., her movements) and an effect (i.e., the camera’s zooming) operating at a distance but within the local space that she could perceive and attend to; she rejected the possibility that someone could do it from far away.

In other cases, it was the evidence from their interventions that allowed students to reason about A@AD. When students witnessed that their actions on the tablet corresponded with images moving on the screen, they concluded that it was possible to operate the camera in Florida from far away. Figure 5 shows that all local responses in this scenario were provided before students manipulated the tablet and that although some students provided A@AD responses before intervening, most A@AD responses were provided after an intervention.

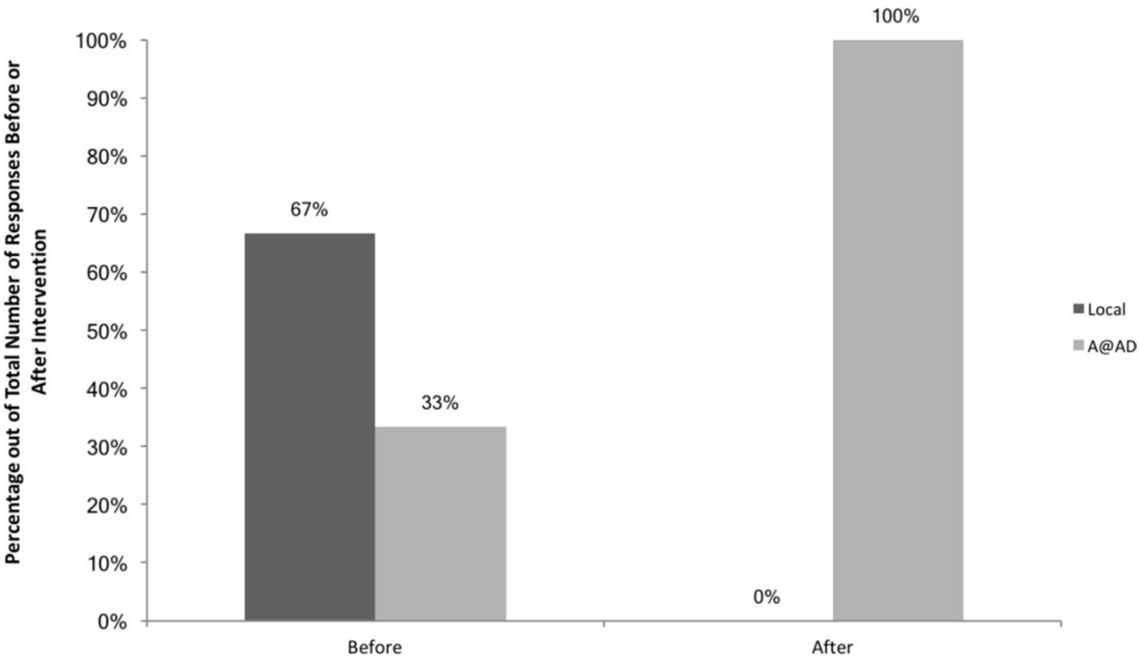

Figure 5. Percentage of Local and A@AD responses given before and after intervention in the tablet scenario

Nayshya was initially ambivalent about whether or not it was possible to operate a camera in Florida using the tablet, but as soon as she saw the results of her intervention on the tablet screen, she expressed "We are moving the camera." Similarly, Cameron changed his conclusion after manipulating the tablet.

I: What do you think? Do you think you're moving the camera?

C: Yeah

I: Can you tell me more about that? What makes you say that?

C: Because I am moving it on the black thing. [Referring to the black rectangle space where camera on the tablet screen is controlled.]

I: You're moving it on the black thing. Okay. Tell me more about that. What are you doing to the black thing to make it move? …to make the camera move?

C: I'm moving it different places.

I: What are you doing to make that happen?

C: I'm, I'm pressing it, with the, how is that happening?

I: What are you pressing buddy?

C: I'm pressing there where on the black where I wanted the yellow thing to go.

Seeing the evidence of their own intervention allowed students to conclude that A@AD was a possible explanation for the phenomenon being observed. The evidence of temporal covariation allowed them to override spatial discontinuity to accept and describe a causal relationship between their actions and the movement of a camera far away. As reviewed, this fits with findings suggesting that temporal covariation plays an important role in causal reasoning and that even preschoolers can override spatial gaps to reason from temporal information.

4. Discussion

Given that previous research has shown that older students have difficulty perceiving and explaining A@AD cases, we were interested in investigating whether young students consider causes and effects acting at an attentional distance as a possible causal explanation. When considering complex environmental or ecological causal phenomena, students may not notice or seek out evidence beyond the immediate attentional space if they do not, first, hold causality at a distance as a possibility. The results demonstrated that young learners are capable of accepting that causes and effects can act at an attentional distance and of building causal explanations based on this possibility. Although students certainly rejected A@AD and had trouble providing explanations in certain instances—as would be expected from extant literature—students also revealed the ability to both accept and explain A@AD. This was enabled by a number of factors, including features of the scenario and students' own cognitive strategies for reasoning about the causality involved.

We were interested in further exploring the features of events that students accept as A@AD and characterizing the nature of their reasoning when responding to scenarios. In general, students seemed to accept and describe action at an attentional distance if they were familiar with the scenario; could think of familiar causes or mechanisms within their attentional repertoire; or observed evidence that helped them think about possible mechanisms that connected causes and effects at an attentional distance. Familiarity with the scenario seemed to support students in recalling prior knowledge and experiences that allowed them to come up with potential causes and effects and, importantly, mechanisms that could help explain causality over large distances. Personal, daily experience and knowledge—firsthand knowledge and possibly testimony from others—about how the loudspeaker worked, helped students accept and explain that someone in the office operated the loudspeaker located in the interview room, even without directly observing the covariation between the cause and effect. The importance of familiarity when considering scenarios suggests that there are certainly knowledge requirements related to mechanisms and the more children hold, the more successful they can be in addressing the lack of covariation information involved in A@AD. When they could not think about potential familiar mechanisms or did not see evidence that supported the claim of A@AD, students in this study often rejected the possibility and provided local explanations or were unable to expand on their acceptance of A@AD as a possible explanation. In unfamiliar cases, such as the cat purse and camera being operated from far away, some students resorted to magical and/or fantastical mechanisms to explain the anomalous phenomena, as has also been reported in previous research (Subbotsky, 2004; Woolley & Cornelius, 2017). The reliance on mechanism has also been observed when older students generate A@AD explanations (Grotzer & Solis, 2015) and appears to be a powerful mode of causal induction that enables students to fill in the lack of covariation information. In this study, mechanism knowledge allowed students to consider covariation between causes and effects, and in this way, mechanism and covariation interacted with one another, as previously argued (Grotzer & Tutwiler, 2014).

Intervening in the actual scenarios, as in the tablet scenario, also appeared to be a powerful cognitive resource that enabled students to accept and reason about A@AD. We were interested in investigating whether providing temporal covariation evidence could override spatial gaps when students reasoned about A@AD, as has been reported in prior research (Kushnir & Gopnik, 2007), and whether this would be especially true when children themselves intervened in the scenario as opposed to simply observing a researcher present the evidence, as has also been reported (Sobel & Sommerville, 2010). We found that, indeed, students attended to the evidence generated by their interventions on the tablet and corresponding changes on the screen that cued them to a relationship between their actions and the behavior of the camera in Florida. Although the camera was located outside of their immediate attentional space, the tablet made the covariation between students' manipulations and the camera movement to be virtually accessible and perceivable to them. This is perhaps a special case made possible by the power of technology, but it indicates the importance of allowing learners to participate in the direct exploration of phenomena and the effectiveness of observational and measurement tools that can elucidate and capture otherwise obscured covariation evidence in A@AD.

The results provide insights into factors that influence young students' ability to accept and reason about A@AD, including the familiarity of the phenomenon, prior knowledge and experience of potential causes, effects, and mechanisms, and the power of direct intervention that can all address the lack of covariation information. However, we acknowledge that there are limitations to the application of these results to real world instances of A@AD. In this interview study, a researcher was drawing students' attention to a cause and potential distant effect. This circumvented the prerequisite that learners in real-world situations face first, in noticing potential causes and effects across attentional spaces, prior to reasoning about them. It is much harder to observe an action and conjure up potential effects at great distances, such as the effect of CO2 emissions and the polar ice melt, unless someone calls our attention to the potential effects. Likewise, when observing local effects, it can be hard to imagine that the cause may be located far away. That young students were able to accept and explain A@AD in this study does not necessarily translate into being able or likely to notice it in their everyday life or find it easier to reason about A@AD when encountering more complex phenomena in science education. Furthermore, students' explanations did not always coincide with their possibility judgments in this study. This is perhaps not surprising given that formulating explanations can be more cognitively demanding for children than simply accepting or rejecting a causal scenario presented by an interviewer. Young students' possibility judgments may not be closely coupled with their causal explanations. However, we believe that by taking both their judgments and explanations as illustrative of their causal considerations, we can gain insights into students' causal reasoning process.

We also acknowledge that some of the unfamiliar tasks in this study involved a degree of experimenter manipulation, not unlike other studies in developmental science, to create the appearance of the A@AD. At first glance, a purse that meows may appear unrelated to phenomena we find in nature. However, many accepted scientific concepts involving action at an attentional distance can also seem fantastical: tides on the Earth are controlled by the moon, satellites stay in orbit as the result of a balance between gravitational force and their forward motion, and distant weather events can impact local watersheds. Taken together, our findings suggest that even young children hold developing understandings that might offer affordances for further learning. This presents promise that instruction could leverage students' existing knowledge and tendencies to facilitate students' A@AD reasoning in and outside the classroom. Future research can investigate both, how young students respond to scientific phenomena that involve A@AD and the effect of instructional interventions in supporting students' awareness and explanations of A@AD phenomena. Furthermore, microgenetic and longitudinal analysis of how A@AD reasoning develops within and between age groups, respectively, could provide insights into how to scaffold students' A@AD causal reasoning.

4.1 Implications

This study investigated whether or not young students accepted A@AD as a causal explanation and were able to provide corresponding explanations in scenarios where the cause and effect resided in different attentional frames. Given the results of this study, the critical question to ask may not be as simple as whether or not young students can reason about action at an attentional distance, but rather, in which instances they are likely to accept, notice, attend to, and understand A@AD. The cognitive resources that the children brought to bear as they reasoned about A@AD in this study were evident in the multiple cognitive strategies and modes of causal induction they employed to make sense of scenarios. These same cognitive strategies (e.g., recalling previous knowledge, reasoning about potential mechanisms, seeking evidence, or intervening in scenarios) can likely be helpful in instructional practices to teach young children about complex scientific phenomena involving A@AD. Early childhood educators can present scientific phenomena, like the tides, climate change, or the spread of disease, that have components of causation at physical and temporal distances, and provide inquiry-based instruction that introduces various potential patterns of causality, including A@AD. Teachers themselves can be more attuned to A@AD in their daily experiences that can serve as examples for students' to engage with and reason about during instruction. And given the results of this study and previous work, learning and leveraging mechanism knowledge and creating a practice that invites students to reflect on their own attentional frames can be helpful in supporting even young students in attenting to and explaining causes and effects across distances (Grotzer & Solis, 2015). Learning that causality can act across great distances is essential to understand in our complex world, especially as we are tasked to address environmental and ecological challenges with long-term consequences. This study contributes to our knowledge of how young learners reason about such concepts and is an early step in generating instructional tools and interventions to support their developing understanding.

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References

Ahn, W. K., Kalish, C. W., Medin, D. L., & Gelman, S. A. (1995). The role of covariation versus mechanism information in causal attribution. *Cognition, 54*(3), 299-352. https://doi.org/10.1016/0010-0277(94)00640-7

Bonawitz, E., Ullman, T. D., Bridgers, S., Gopnik, A., & Tenenbaum, J. B. (2019). Sticking to the evidence? A behavioral and computational case study of micro-theory change in the domain of magnetism. *Cognitive Science, 43*(8). https://doi.org/10.1111/cogs.12765

Buchanan, D. W., & Sobel, D. M. (2011). Mechanism-based causal reasoning in young children. *Child Development, 82*(6), 2053-2066. https://doi.org/10.1111/j.1467-8624.2011.01646.x

Bullock, M., Gelman, R., & Baillargeon, R. (1982). The development of causal reasoning. In W. J. Friedman (Ed.), *The developmental psychology of time* (pp. 209-254). New York: Academic Press.

Charmaz, K. (2002). Qualitative interviewing and grounded theory analysis. In J. F. Gubrium & J. A. Holstein (Eds.), *Handbook of interview research: Context & method* (pp. 675-694). Thousand Oaks, CA: SAGE Publications, Inc.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. Thousand Oaks, CA: SAGE Publications, Inc.

Corriveau, K. H., & Harris, P. L. (2010). Preschoolers (sometimes) defer to the majority in making simple perceptual judgments. *Developmental Psychology, 46*(2), 437-445. https://doi.org/10.1037/a0017553

Gentner, D., & Maravilla, F. (2018). Analogical reasoning. In L. J. Ball & V. A. Thompson (Eds.), *International handbook of thinking & reasoning* (pp. 186-203). New York, NY: Psychology Press.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*, 306-355. https://doi.org/10.1016/0010-0285(80)90013-4

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15*(1), 1-38. https://doi.org/10.1016/0010-0285(83)90002-6

Gopnik, A., & Bonawitz, E. (2015). Bayesian models of child development. *Wiley Interdisciplinary Review Cognitive Sicence, 6*(2), 75-86. https://doi.org/10.1002/wcs.1330

Gopnik, A., Glymour, C., Sobel, D. M., Schulz, L. E., Kushnir, T., & Danks, D. (2004). A theory of causal learning in children: Causal maps and Bayes nets. *Psychological Review, 111*(1) 3-32. https://doi.org/10.1037/0033-295X.111.1.3

Gopnik, A., & Schulz, L. (2007). *Causal learning: Psychology, philosophy, and computation*. New York, NY: Oxford University Press.

Gopnik, A., Sobel, D. M., Schulz, L. E., & Glymour, C. (2001). Causal learning mechanisms in very young children: Two-, three-, and four-year-olds infer causal relations from patterns of variation and covariation. *Developmental Psychology, 37*(5), 620-629. http://doi.org/10.1037/0012-1649.37.5.620

Griffiths, T. L., Soberl, D. M., Tenenbaum, J. B., & Gopnik, A. (2011). Bayes and blickets: Effects of knowledge on causal induction in children and adults. *Cognitive Science, 35*(8), 1407-1455. https://doi.org/10.1111/j.1551-6709.2011.01203.x

Grotzer, T. A., & Solis, S. L. (2015). Action at an attentional distance: A study of children's reasoning about causes and effects involving spatial and attentional discontinuity. *Journal for Research in Science Teaching, 52*(7) 1003-1030. https://doi.org/10.1002/tea.21233

Grotzer, T. A., & Tutwiler, M. S. (2014). Simplifying causal complexity: How interactions between modes of causal induction and information availability lead to heuristic driven reasoning. *Mind, Brain, and Education, 8*(3), 97-114. https://doi.org/10.1111/mbe.12054

Harris, P. L. (2012). *Trusting what you're told: How children learn from others*. Cambridge, MA: Belknap Press/Harvard University Press.

Harris, P. L., & Corriveau, K. H. (2011). Young children's selective trust in informants. *Philosophical Transactions: Biological Sciences, 366*(1567), 1179-1187. https://doi.org/10.1098/rstb.2010.0321

Keil, F. C. (1994). The birth and nurturance of concepts by domains. In L. A. Hirschfield & S. A. Gelman (Eds.), *Domain specificity in cognition and culture* (pp. 234-254). New York: Cambridge University Press.

Kushnir, T., & Gopnik, A. (2007). Conditional probability versus spatial contiguity in causal learning: Preschoolers use new contingency evidence to overcome prior spatial assumptions. *Developmental Psychology, 43*(1), 186-196. https://doi.org/10.1037/0012-1649.43.1.186

Legare, C. H., & Clegg, J. M. (2015). The development of children's causal explanations. In S. Robson & S. Flannery Quinn (Eds.), *The Routledge international handbook of young children's thinking and understanding* (pp. 65-74). New York, NY: Routledge.

Schulz, L. E., Gopnik, A., & Glymour, C. (2007). Preschool children learn about causal structure from conditional interventions. *Developmental Science, 10*(3), 322-332. https://doi.org/10.1111/j.1467- 7687.2007.00587.x

Shultz, T. R., & Mendelson, R. (1975). The use of covariation as a principle of causal analysis. *Child Development, 46*(2), 394-399. https://doi.org/10.2307/1128133

Siegler, R. S. (1976). The effects of simple necessity and sufficiency relationships on children's causal inferences.

Child Development, 47(4), 1058–1063. https://doi.org/10.2307/1128443

Sobel, D. M., & Buchanan, D. W. (2009). Bridging the gap: Causality-at-a-distance in children's categorization and inferences about internal properties. *Cognitive Development, 24*(3), 274-283. https://doi.org/10.1016/j.cogdev.2009.03.003

Sobel, D. M., & Legare, C. H. (2014). Causal learning in children. *Wiley Interdisciplinary Review Cognitive Sicence, 5*(4)*,* 413-427. https://doi.org/10.1002/wcs.1291

Sobel, D. M., & Sommerville, J. A. (2010). The importance of discovery in children's causal learning from interventions. *Frontiers in Developmental Psychology, 1*, 176-183. https://doi.org/10.3389/fpsyg.2010.00176

Sobel, D. M., Tenenbaum, J. B., & Gopnik, A. (2004). Children's causal inferences from indirect evidence: Backwards blocking and Bayesian reasoning in preschoolers. *Cognitive Science, 28*(3), 303-333. https://doi.org/10.1016/j.cogsci.2003.11.001

Spelke, E. S., Phillips, A., & Woodward, A. L. (1995). Infants' knowledge of object motion and human action. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 44-78). Clarendon Press: Oxford.

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques* (2nd ed.). Thousand Oaks, CA: SAGE Publications, Inc.

Subbotsky, E. (2004). Magical thinking in judgments of causation: Can anomalous phenomena affect ontological causal beliefs in children and adults? *British Journal of Developmental Psychology, 22*(1), 123-152. https://doi.org/10.1348/026151004772901140

Woolley, J. D., & Cornelius, C. A. (2017). Wondering how: Children's and adults' explanations for mundane, improbable, and extraordinary events. *Psychonomic Bulletin & Review, 24*(5), 1586-1596. https://doi.org/10.3758/s13423-016-1127-1

Young, G. (2016). *Unifying causality and psychology: Being, brain, and behavior*. Switzerland: Springer International Publising.

Notes

Note 1. In Grotzer & Solis (2015) we used the term "distal" to refer to student responses that were beyond the local attentional space, including both distant and A@AD responses. In this paper, we chose to separate distant and A@AD responses in coding.

Note 2. Pseudonyms used throughout. In interview excerpts, the first letter of the students' name is used and "I" refers to interviewer.