Thinking about play: Young children's spontaneous experiments and scientific reasoning

Audrey K. Kittredge
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
1-607-351-7518
audreyk@andrew.cmu.edu

David Klahr
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
1-412-268-3670
klahr@andrew.cmu.edu

Kevin Willows
Synaptek Research
1188 Ostler Court
Mississauga, Ontario L5C 3G6
1-647-213-2347
kevinwillows@gmail.com

ABSTRACT
This paper explores the relationship between young children's ability to spontaneously generate controlled experiments in free play, and more explicit scientific reasoning skills, such as describing causal relationships learned through experimentation. Children aged 4-6 played with objects in a touchscreen tablet app game. Most of these children spontaneously produced controlled experiments that disambiguated cause-effect relationships between objects in the game. The large majority of children who produced controlled experiments mentioned their discoveries in reply to subsequent open-ended questions ("What did you find out when you were playing just now?", or one of two follow-up questions, "What do you think makes the machine go?" and "Show me how the toy touches the machine and makes it go"). These findings suggest that young children tend to self-report causal learning from their own spontaneous controlled experiments.

Categories and Subject Descriptors
J.4 [**Computer Applications**]: Social and Behavioral Sciences – *psychology.*

General Terms
Design, Experimentation.

Keywords
Experimentation, causal reasoning, scientific reasoning, preschool, science education.

1. INTRODUCTION
Scientists satisfy curiosity through experimentation. In particular, "controlled experimentation" (carrying out investigations that isolate one causal variable at a time) is a critical skill in mature scientific reasoning. Although full mastery of controlled experimentation is still lacking in elementary school students [1], there is increasing evidence that while freely playing with objects, preschoolers are capable of spontaneously performing simple controlled experiments to isolate causal variables [2] [3] [4]. The spontaneity of young children's experimentation suggests that they are motivated to engage in such behaviors, perhaps driven by curiosity. Investigating the relationship between spontaneous play-based experimentation and more verbal scientific reasoning abilities may enhance our understanding of how to support students' curiosity in early childhood science education.

The disconnect between preschoolers' ability to produce spontaneous experiments, and the effortful experimentation of older children, has led to proposals that young children's play-based experimentation is the product of simple heuristics to reduce causal complexity [5]. To what extent can young children engage in articulable scientific reasoning about their spontaneous experiments? In this paper, we focus specifically on the extent to which children learn from their own play-based controlled experiments, and can articulate this learning through language.

2. SPONTANEOUS EXPERIMENTATION IN PRESCHOOL CHILDREN
Several studies have documented controlled experiments in the course of preschoolers' free play [2] [3] [4]. For instance, Cook, Goodman and Schulz (2011) showed children four plastic beads that could be snapped together and apart. They also showed children that only two of the four beads made a "machine" activate (causing it to light up and play music). Children were then shown two new joined beads that could not be pulled apart. Children were then given a demonstration of how the machine activated when the joined beads were placed horizontally on its surface. When children were then left alone with the machine and the joined beads for 60 seconds, 45% of children produced controlled experiments (orienting the joined beads vertically and touching each bead separately to the machine). Critically, these experiments were generated more often after children witnessed causally ambiguous evidence: when children saw that all four of the training beads activated the machine (removing the implication that some beads might not activate the machine), only 5% of children generated controlled experiments (see also [3]). Children are also more likely to generate controlled experiments in their play after witnessing belief-violating evidence [4].

3. LEARNING FROM SPONTANEOUS EXPERIMENTS
Only a few studies have evaluated children's learning from their own play-based experiments, asking children to make simple physical and verbal predictions that could reveal knowledge gained from experimentation [4] [6] [7]. Only one study probed children's knowledge with an open-ended question: asking 6-7 year-olds to explain how an asymmetrical block balanced on a post [7]. In these studies, some, but not all preschool children evince learning about cause-effect relationships present in the physical materials they play with. However, as these studies have

always asked children explicitly about the cause-effect relationships of interest, it is unclear how readily children might report them on their own. The current study attempts to address this issue by asking children to report what they have learned, without specifying a topic. Moreover, we begin by asking children open-ended questions and gradually progress to more specific questions. This allows us to probe the variability in children's ability to articulate their learning from spontaneous experiments, which is critical for understanding how these experiments might be leveraged to support early childhood science education.

4. METHODS

We asked 38 4-6 year-old children (mean age = 5.5 years) to play a touchscreen tablet version of Experiment 2 from Cook, Goodman and Schulz (2011). Children were introduced to a virtual world in which objects float on "water". Children were first shown how to move a sample object on the screen (Figure 1, phase 1). Children were then shown 4 blocks, and were allowed to play with these blocks (Figure 1, phases 2-3). Then children were shown that half of the blocks (*Some* condition, n = 19) or all of the blocks (*All* condition, n = 19) activate a "special underwater machine" upon contacting it, making it light up and play music (Figure 1, phase 4). Children were then shown a "toy" consisting of two blocks that are stuck together, and are allowed to play with the toy (Figure 1, phases 5-6). Finally, children were shown that when placed horizontally on the machine, the stuck blocks activate the machine (Figure 1, phase 7). Then children were left alone to play with the stuck blocks and the machine (Figure 1, phase 8). We videorecorded children's play and code it for the presence of "controlled experiments" that test the causal efficacy of each block separately. We define a controlled experiment as (a) rotating the stuck blocks so that only one block touched the machine at a time, or (b) sliding the stuck blocks off the sides of the machine so that only one block at a time touches the machine. (We engineered the game so taht the first block tested on its own did not activate the machine, while the second block tested on its own did.) Afterwards, we assessed children's learning from their play (Figure 1, phase 9) by asking them a series of questions. Importantly, the first question ("What did you find out when you were playing just now?") was open-ended and did not explicitly target the cause-effect relationships between individual blocks and the machine. If children did not mention how the blocks activate the machine in response to the first question, they were asked a more specific second question ("What do you think makes the machine go?"). If children did not refer to how the blocks activate the machine in response to the second question, they were given an even more targeted third prompt ("Show me how the toy touches the machine and makes it go").

5. RESULTS

Preliminary analyses indicate that 73.7% of the children were "Experimenters", i.e. they performed at least one controlled experiment during the 60 seconds of free play. Children were slightly more likely to generate a controlled experiment following the causally ambiguous evidence provided in the Some condition, compared to the All condition (however, this difference between conditions was not significant, 84% Some v 63% All). The majority (71.4%) of the Experimenters described at least some of the cause-effect relationships uncovered in their play when questioned after the free play period: 50% in response to the first question, 17.9% in response to the second question, and 3.6% in response to the third question.

6. DISCUSSION AND CONCLUSIONS

Our results suggest that most 4-6 year-old children produce spontaneous experiments in a tablet-based app. Importantly, this extends prior work on spontaneous experimentation with physical objects (e.g. Cook et al., 2011) to the realm of touch-screen technology. We believe that children's high rate of experimentation (73.7% in our study, v 45-50% in Cook et al.) is due to the specific affordances of our virtual environment. In Cook et al. (2011), children had to spontaneously come up with the idea of rotating the stuck blocks toy (required for producing a controlled experiment). In contrast, rotation was almost a feature of the stuck blocks in our virtual environment: if children touched the middle of the toy, it remained horizontal, but if they touched one end of the toy, it rotated. Thus in our study, some children could have rotated the toy without intending to, seeing that it did not activate the machine, and become inspired to complete a controlled experiment by trying the other side of the toy.

These same affordances may also explain why we did not find a significant difference between the Some and All conditions, unlike Cook et al. (2011). It is possible that causal ambiguity specifically inspired children to think of rotating the toy in Cook et al. (2011), leading to the difference between the Some and the All conditions. If so, then the fact that children did not need to invent the idea of rotating the toy in our experiment predicts that there would not be much of a difference between conditions. Importantly, however, we believe that the controlled experiments in our study were not purely generated by chance. Experimenters in our study had seen that one side of the toy did not activate the machine, and several other studies have shown that children are more likely to generate controlled experiments after causally ambiguous or belief-violating evidence [2] [4]. We are currently conducting a follow-up study to confirm this interpretation.

We found that when asked to describe what they have learned from their play ("What did you find out when you were playing just now?"), about 50% of young children choose to describe the cause-effect relationships revealed in the course of their experimentation. This suggests that these children either purposefully reported information that was relevant to the experimenter's curiosity ("I wonder what makes the machine go?"), or that children were inherently motivated to report their causal learning. Nearly one fifth of children only required one additional, more specific prompt ("What do you think makes the machine go?") to report the cause-effect relationships they observed in their play. This suggests that most young children can not only learn from controlled experiments in their own play, but are motivated to verbally articulate this learning when given a choice of what to report.

Why did 28.6% of the children never report the cause-effect relationships they discovered in the course of their controlled experiments? It is possible that such young children either did not attend to or remember the causal outcomes of their experiments. Alternatively, some children's verbal abilities may have been too limited to express their knowledge, or they may not have

understood that we were interested in all the ways that the toy could activate the machine. Finally, some children may have thought that this information was not particularly salient or interesting.

Taken together, these findings suggest that while there is significant individual variability among children, most 4-6 year-olds can report what they've learned from their own spontaneously generated controlled experiments in a touchscreen tablet game. This suggests that digital implementations of causal learning paradigms may be a promising a platform for the assessment and promotion of children's verbal scientific reasoning and curiosity.

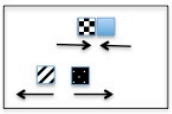
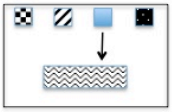
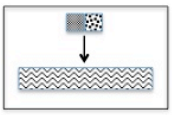
Experiment phase	Description	Schematic of tablet screen
1. Training phase	Children are shown how to "move" objects on the tablet	
2. Four blocks introduction	Experimenter shows children 4 blocks that can be stuck together and then unstuck.	
3. Four blocks play	Children play with the 4 blocks.	
4. Four blocks and machine demonstration	Experimenter shows children that 2 of the 4 blocks activate a rectangular machine (making it light up and play music).	
5. Stuck blocks introduction	Experimenter shows children two novel blocks that can't be unstuck.	
6. Stuck blocks play	Children play with the stuck blocks.	
7. Stuck blocks and machine demonstration	Experimenter activates the machine with the stuck blocks (simultaneously touching both blocks to the box), saying, "I wonder what makes the machine go?"	
8. Stuck blocks and box play	Children play with the blocks and machine for 60 seconds	
9. Post-test questions	Experimenter asks questions to assess children's knowledge of causal relationships between the blocks and the machine.	

Figure 1. Experimental procedure

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