The Dimensions of Reflection Coding Scheme: A New Tool for Measuring the Impact of Designing for Reflection in Early Childhood

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ABSTRACT

Reflection is a metacognitive skill that's essential to creative discovery. As we design interactive technologies for reflection, how might we measure the impact of our designs? In this paper, we develop a coding scheme to explore reflective moments in the speech and language of young children during child-computer interaction. Using cross-disciplinary theories — from the learning sciences to cognitive neuroscience — we define and describe 13 reflective processes occurring within Baumer's 3 conceptual dimensions of reflection. We then use this framework to measure the impact of a child-robot storytelling interaction with twelve children ages 4–5, and offer developmentally-appropriate transcript examples for each of the 13 reflective processes. This coding scheme provides a practical tool for exploring the impact of our designs on reflection, and can be used to guide design iteration.

CCS CONCEPTS

• **Human-centered computing → HCI design and evaluation methods**; **Empirical studies in HCI**.

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reflection, cognition, storytelling, coding scheme, interaction design & children, early childhood

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1 INTRODUCTION

Reflection is a powerful way to support both creative and cognitive development, because when we reflect, we re-examine a situation and combine information in new ways to deepen our understanding [4, 91]. But reflection, like other neurocognitive skills, is experience-dependent. With repeated use, the neural systems underlying reflection become more efficient [28, 54], allowing us time to engage our reflective processes before responding or reacting [4]. Thus, not only is reflection itself an iterative process, it's a skill that must be strengthened through practice. To support reflective practice, human-computer interaction researchers are increasingly designing tools to scaffold reflection in adults and children alike [6, 7]. And while researchers have contributed measures for evaluating adult reflection across a range of fields and contexts, we lack frameworks for exploring reflection in early childhood. Without tools for exploring reflection, interaction designers are limited in our ability to examine the impact of our designs and effectively iterate on our prototypes.

To support our community in measuring the impact of our designs within iterative design cycles, we developed a *Dimensions of Reflection Coding Scheme* for examining reflection in the speech and language of young children, and used the resulting scheme to examine the ways in which young children reflect during child-robot interaction. To develop the reflection measure, we surveyed theories on reflection from neuroscience, cognitive science, education, philosophy, and human-computer interaction. Using these theoretical contributions, we illustrate the ways in which reflective processes are exhibited within Baumer's three dimensions of reflection [6]: Breakdown, Inquiry, and Transformation. We then use the *Dimensions of Reflection Coding Scheme* to explore the ways that young children engage in metacognitive reflection when prompted by a conversational robot. During the child-robot interaction, a stuffed animal robot asks open-ended questions to support young children in telling inventive stories about their creative play. By examining reflection within storytelling approaches and responses to the robot's questioning, we share design implications for supporting young children's reflection — through the use of open-ended questioning and scaffolded storytelling, as well as through imaginative and creative play. We conclude by describing how human-computer interaction designers can use the *Dimensions of Reflection Coding Scheme* to measure the impact of our reflective interaction designs.

2 RELATED WORK

To develop a coding scheme for reflection, we first examine theoretical contributions to ground our understanding of the metacognitive process. Next, we survey existing technologies that aim to support reflection in children, and highlight the need for a framework to aid the iterative design and implementation of these technologies. Finally, we explore cross-disciplinary coding schemes for reflection, and observe that few such measures explore reflection in children. Taken together, we motivate our development of a novel coding scheme to examine reflection in young children.

2.1 Dimensions of Reflection

In a review of theories underlying reflection — as well as human-computer interaction technologies that aim to support reflection [7] — Baumer categorized three dimensions of reflection: Breakdown, Inquiry, and Transformation [6]. In the learning sciences, Oosterbaan et al. similarly described how doubt or uncertainty triggers a reflective process, wherein further analysis serves to increase knowledge and possibly transform one's perspective [61]. These three dimensions are also echoed in Zelazo's work on the neural correlates of reflection, wherein information is iteratively reprocessed in the brain's prefrontal cortex, then combined with other information to form a more elaborate knowledge representation [91]. This interdisciplinary alignment of breakdown, inquiry, and transformation suggests potential for examining reflection using this three-dimensional approach.

2.1.1 Breakdown. The philosopher Donald Schön notes that reflection begins with "surprise, puzzlement, or confusion in a situation which [we] find uncertain or unique" [71]. Dewey similarly observed that reflection is "evoked by a state of doubt" [22] — a sentiment shared by the sociologist Mezirow who observed how "disturbing anomalies" are catalysts for reflection [57]. At the neural level, a key trigger for reflection is noticing conflict [28], noticing challenges [92], and detecting uncertainty [4], each of which can serve to interrupt automatic processing. This pause initiates the iterative reprocessing of information "via neural circuits that coordinate hierarchically arranged regions" of the prefrontal cortex [91]. Almy and Zelazo describe how breakdown and iteration support reflection: "Once children detect a problem, they can pause, interrupting the momentum of their behavior, and reflect on the task" [4]. From an interaction design perspective, taking a "step back" [1, 65] can foster reflection, and can be instigated by asking authentic questions [65]. Not only can asking open-ended questions help students detect problems [60], but asking questions such as *"What's been most surprising to you?"* can interrupt habitual speech and trigger deeper reflection [65]. These examples demonstrate the role of *Breakdown* in triggering a reflective cycle.

2.1.2 Inquiry. During inquiry, continues Schön, we "reflect on the phenomenon before [us], and on the prior understandings which have been implicit in [our] behaviour" [71]. Here, more details, aspects, and contexts are noticed [55, 90–92], allowing one to make connections between ideas [65]. Inquiry is an active process [45, 65], where one might "think about possible solutions to a problem" [4], generate hypotheses [22], and test ideas through experimentation [65, 71]. Creative activity may itself be a form of inquiry. The act of sketching and drawing allow us to "reflect-in-action" [70], by providing an avenue for visualizing concepts, organizing our cognitive activity, facilitating problem solving, and manipulating both our artifacts and our ideas [25]. At the neural level, "previously processed information from the limbic regions is additionally and concurrently processed by cortical regions," and this active reprocessing allows for more aspects of a situation to be noticed and integrated into our knowledge representations [4]. Through inquiry, "children increase the range of aspects of the situation to which they may respond" [55].

2.1.3 Transformation. During transformation, says we Schön, we "carry out an experiment which serves to generate both a new understanding of the phenomenon and a change in the situation" [71]. This process results in a conclusion [22] or a deeper understanding [28, 34, 65, 91], as well as new perspectives [61], solutions [4], ideas [65], decisions [4, 65], and directions [65]. Here, we can override our habits [55] and adjust our actions with new behaviors [54, 55, 61, 81]. In this way, we are able to liberate [55] ourselves through "emancipatory knowledge" [61]. Similar to breakdown and inquiry, open-ended questions can support transformation. For example, by asking open-ended *"Why?"* questions, facilitators can foster reflection by helping students discover design problems, articulate design rationale, and "focus on future solutions" [60]. At the neural level, the detection of conflict that occurs during a breakdown triggers reflective inquiry wherein knowledge structures increase in their complexity [27, 28]. These complex knowledge structures integrate more nuance and context into their representation [4, 91], resulting in a transformation wherein conflict is resolved [27, 28]. This process allows for "more flexibility and control in a wider range of situations than previously possible" [4]. Because "reflection unfolds in time through a series of iterations" [91], the transformed understanding can become itself the object of breakdown and inquiry in subsequent iterations. These cross-disciplinary dimensions of *Breakdown*, *Inquiry*, and *Transformation* can help us characterize how reflection might be developed and expressed.

2.2 Reflective Technologies for Children

In the field of human-computer interaction, researchers are increasingly designing technologies to support reflection [6, 7]. Just as we might design tools to aid teachers in reflecting on their own teaching [5] and on their students' learning [49], there is growing attention to supporting children in reflection too. Although these reflective technologies span a range of forms, contexts, and purposes — storytelling and narration is a central theme across many designs. Designers of reflective technologies use interactive storytelling to reflect with food [15], toys [37], puppets [2], and tangibles [62]. Designers aim to support reflection through collaborative authoring [75], and multilingual storytelling [40, 42], as well as audio narration [2] and storytelling with a robot [38, 39, 41]. Reflecting through storytelling is used to support co-design [50], roleplaying [85], introspection [9], creativity [64], and learning through play [38, 39, 41].

In addition to storytelling's use as a reflective tool for learning about math [3], science [17], and internet privacy [50], storytelling is used to help children reflect on family health practices [68], disease management [78], pediatric rehabilitation [51], empathy [59], and emotions [67]. From open-ended play to curricular learning, it's evident that storytelling is seen as a powerful tool to engage young children in reflection.

Many of these systems for reflection are grounded in the cyclical design practices of human-centered design and human-computer interaction — wherein designers develop or co-design a prototype and conduct usability testing to gather data on its use. The resulting insights inform design iteration. Yet most of these interactive systems lack methods for robustly evaluating their impact on reflection [6, 7], especially reflection in children. To support effective iteration, our field needs tools for closely examining reflection itself. Since many of these interactive systems involve storytelling and narration in real-world contexts, exploring reflection in the speech and language of children may serve as a practical tool.

2.3 Measuring Reflection in Speech and Language

Speech and language serves as a window to the mind, and can be authentically witnessed in real-world contexts — without reliance on laboratory neuroimaging. The fields of education, linguistics, and the learning sciences have been steadily making progress on developing coding schemes for identifying reflection in the speech and language of adults. Whether involving the analysis of oral speech [33, 36], written language [52, 77], or both [11, 82], these frameworks and coding schemes are often used to assess levels of reflection and examine the impact of curriculum on reflective practice.

Researchers have developed measures to evaluate reflection in blog posts [14, 69], essays [84, 89], journals [8, 13, 53], interviews [33, 43], portfolios [20, 61, 79], classroom dialogue [36, 82], questionnaires [48, 77], and in both online [35, 46] and live interactions [74]. For example, Savicki & Price [69] examined college students' blog posts for linguistic indicators of reflection — such as words that map to cognitive and affective states associated with reflection — in order to understand how students reflected during critical moments of their study abroad experiences.

Yet the vast majority of these coding schemes for measuring reflection are focused on the speech and language of adults — mainly in higher education contexts including teacher training [29, 79] and medical training [21, 77], as well as in professional development contexts for teachers [21, 58], doctors [52], and professors [56]. Only a few methods focused on measuring reflection in the speech and language of youth, specifically with high schoolers [83, 88], and middle schoolers [32, 36, 87] — leaving all of early and middle childhood unsupported.

Our team initially explored modifying these existing frameworks for use with young children, however, we encountered several challenges with this approach. First, many of the reflection frameworks we found were not documented with enough specificity to be used and reproduced. Second, many of the reflection frameworks were context-specific — e.g., for reflecting on the scientific method, or reflecting on learning-by-teaching strategies — and could not be flexibly adapted for the open-ended, playful contexts of young children. Third, many of the reflection frameworks involved specific forms of reflection that are not well-aligned with developmentally appropriate practices in early childhood, such as reflecting on one's own belief systems. To effectively evaluate the impact of interaction design on reflection in early childhood, frameworks for reflection must take the needs, contexts, and communication patterns of young children into account. Thus, we saw the need to create a well-documented, child-centered coding scheme that can be used across diverse contexts.

3 METHODS

In this study, we develop a coding scheme for examining reflective processes across three conceptual dimensions of reflection. We apply the resulting coding scheme to child-robot interaction transcripts from a prior data collection, in order to test the scheme for inter-rater reliability. Importantly, by analyzing young children's speech in a child-robot storytelling activity using the scheme, we gather developmentally-appropriate transcript examples of the ways in which young children reflect. We start by describing the data collected in the child-robot interaction study, then detail our methods for developing the coding scheme, and finally describe how we coded the child-robot interaction transcripts.

Figure 1: A graphic of the child-robot interaction. A mobile application running the voice interaction is inserted into a stuffed animal to create an interactive robotic object (IRO). The robot asks open-ended questions to support children in reflecting on their creative play through storytelling.

3.1 Child-Robot Storytelling Activity

3.1.1 Participants. This coding scheme was applied to 12 child-robot interaction transcripts from a prior study [39], with children ages 4–5 years old (M = 5.33, 6 females and 6 males). Participants resided in 4 states across the U.S. (Colorado, Illinois, Michigan, and Texas). This was a remote study conducted via Zoom in the participants' homes.

3.1.2 Activity Design.

(1) Setup: From their own homes, parents collected creative materials — such as crayons, paint, paper, glue, scissors, blocks, bricks, and magnets — and arranged them on a table or desk for the creative activity. Children collected a stuffed animal to use for the storytelling activity.
(2) Creative Activity: Children used their creative materials to freely create for 5 minutes. They were given examples prompts (such as a forest, a lake, your school, or your family) yet could make anything they wanted, and could also create with their parents if desired.
(3) Storytelling Activity: Children were instructed to choose a stuffed animal and place it on top of their smartphone *"to make your stuffed animal talk."* A facilitator then remotely operated the voice application. The stuffed animal robot asked questions to help the child reflect on their creative play through storytelling.

3.1.3 Child-Robot Interaction Design. To facilitate creative storytelling, a conversational robot asks open-ended questions to scaffold young children in telling a story about their creative play (Figure 1). The child-robot interaction design is informed by a series of formative studies in preschool classrooms [38, 40, 42]. To adapt the child-robot interaction for a remote study during the COVID-19 pandemic [39], children placed their stuffed animal atop a smartphone at home and a facilitator remotely cued the robot's voice.

To start the child-robot interaction, the stuffed animal robot introduces itself to the child, *"Hi, I'm the story helper. I will help you tell a story about what you made. I will ask you lots of questions to help you tell a story."* Throughout, the robot uses open-ended 'wh-' questions to elicit children's verbal expression. For example, the robot initiates storytelling by asking *"What did you make?"* and *"Tell me a story about what you made."* The robot proceeds by asking scaffolded questions to guide the child in reflecting on their creative play through storytelling. By saying *"The end"* or *"I'm all done,"* the child signals to the robot to end their storytelling session. The robot then asks the child to name their story to guide the child in synthesizing their story's theme. Finally, the robot transitions the interaction by asking a series of reflective questions to foster iteration, including *"Next time you make something, what are you going to make?"* and *"Next time you tell a story, what is it going to be about?"* In this study, children told a variety of stories — from describing something they created to retelling family memories to inventing imaginative tales [39].

3.2 Developing a Child-Centered Coding Scheme for Reflection

To develop an exploratory coding scheme for reflection in early childhood, we grounded our work in the three conceptual dimensions of reflection from the field of human-computer interaction [6], as well as foundational texts from philosophy [71], cognitive neuroscience [91], and the learning sciences [61] that similarly describe reflection with three overarching components. These foundational texts were selected from multiple fields to provide an interdisciplinary foundation for our exploratory literature review. We then used backward and forward snowball sampling on each of these foundational texts to discover related work on reflection. Our inclusion criteria for the exploratory literature review required a definition of reflection or a description of a reflective process that is related to at least one of the three conceptual dimensions of reflection — Breakdown, Inquiry, and Transformation. With this snowball sample, the first author, second author, and third author conducted a scoping literature review to extract the definitions and descriptions of reflective processes from these compiled works.

After gathering 101 definitions, descriptions, and explanations of reflection, we then used thematic analysis techniques to characterize the processes occurring within each of the three dimensions of reflection. Thematic analysis [10, 18] is a qualitative analysis technique used in both psychology and interaction design [12, 76] to iteratively code, cluster, and generate themes from data. After generating initial codes from the definitions, we then iteratively clustered the codes to develop an understanding of distinct reflective processes. This method resulted in 13 reflective processes — 3–5 per dimension — and a coding scheme that describes each process in detail (Tables 1, 2, 3, and 4).

3.3 Coding the Child-Robot Interaction Transcripts

The first, second, third, and fourth authors coded the transcripts using the resulting *Dimensions of Reflection Coding Scheme.* For each story transcript, each author independently coded the child's responses to the robot's prompting. The authors coded each response to the robot with the highest level of reflection observed in that response: *Non-Reflective*, *Reflective Breakdown*, *Reflective Inquiry*, or *Reflective Transformation.* Sometimes children provided single word responses, and at other times children provided multi-sentence responses. We provided an explanation of how that dimension was observed using words, phrases, and sentences as indicators. After independently coding all transcripts, we then met to discuss our coding and resolve (or retain) differences as needed. Finally, we calculated inter-rater reliability using Fleiss' kappa. The kappa statistic was originally developed by Cohen [19] to measure the agreement between two raters, and Fleiss' kappa extends this measure by allowing any number of raters to provide categorical ratings [30]. Fleiss' kappa provides a measure for understanding the extent to which the observed agreement between multiple raters exceeds what would be expected by random chance [31].

Table 1: An Overview of the Dimensions of Reflection Coding Scheme

	Dimension	Processes	Explanation of Dimensions
1	**Breakdown**	Pausing Noticing Revisiting Uncertainty Conflict	*In the first dimension of reflection, a breakdown occurs. We pause and iteratively reprocess (or revisit) information, as we encounter a phenomena, focus our attention, share uncertainty, or detect a conflict.*
2	**Inquiry**	Gathering Data Connecting Data Thinking it Through Experimentation	*In the second dimension of reflection, inquiry occurs. We gather data, build connections, experiment, and actively deliberate. This is an active process but is not the end result.*
3	**Transformation**	Explanations Ideas & Solutions Decisions & Directions Resolution	*In the third dimension of reflection, transformation occurs. We transform our understanding, explain our reasoning, share insights, change directions, synthesize our findings, or discover a solution. This step builds on previous steps — and is distinguished from inquiry because it transforms or resolves a prior inquiry.*

4 FINDINGS

4.1 Dimensions of Reflection Coding Scheme

Through a cross-disciplinary analysis of literature on reflection, we developed and tested the *Dimensions of Reflection Coding Scheme* for examining the reflective processes occurring within each of the three dimensions of reflection. To demonstrate the reliability of this coding scheme, the first four authors tested the scheme on 12 child-robot interaction transcripts. Fleiss' kappa is calculated at 0.7623 resulting in substantial agreement (5/6). A score of (5/6) suggests a high agreement with level 5 of 6 agreement levels.

In Table 1, we provide an overview of each of the three dimensions of reflection in our coding scheme: Breakdown, Inquiry, and Transformation. And in Tables 2, 3, and 4, we extend our explanations by characterizing the reflective processes that comprise each dimension. Together, these tables outline the *Dimensions of Reflection Coding Scheme.*

4.2 Identifying Reflection in Children's Storytelling

Using the *Dimensions of Reflection Coding Scheme*, we analyzed the ways that young children reflect while storytelling in response to a robot's prompting. The twelve children had a total of 260 responses (or non-responses) to the robot, with a minimum of 12 conversational turns, a maximum of 44 conversational turns, and a median of 19.5 conversational turns with the robot. Here, a conversational turn constitutes the robot asking a question and the child giving a response (or not responding). The robot continues to ask questions until the child says *"The End"* or *"I'm all done."* This triggers the robot to ask a few final questions before saying *"Goodbye."*

Of the 260 responses to the robot: 29 (11.15%) were *Non-Reflective* and 231 (88.85%) were *Reflective* (Table 5). Non-reflective responses included times where the child simply did not respond to the robot, as well as phrases that served other purposes, such as saying *"I'm all done"* or *"Bye, robot!"* Across all 260 responses, 69 (26.54%) responses were coded as *Reflective Breakdown*, 119 (45.77%) were coded as *Reflective Inquiry*, and 43 (16.54%) were coded as *Reflective Transformation.* This high proportion of reflective responses (88.85%) within the child-robot interaction is due to the act of labeling. Labeling, part of the *Reflective Breakdown* process of **noticing**, is itself a method for engaging reflection on the thing being labeled — by making it an explicit object of consideration [55]. For example, children might start their child-robot interaction by labeling the elements of their creation. Through scaffolded robot questioning, children then begin to express *Reflective Inquiry* by connecting ideas or experimenting with their materials. As children develop their understanding, they might engage in *Reflective Transformation* by resolving conflict or iterating on their design. However, even some of the children's initial responses to the robot were transformative, as they explained their insights from their creative activity just prior. Next, we share examples from the child-robot interaction transcripts for how reflective processes might be expressed within each dimension.

4.2.1 Reflective Breakdown: Transcript Examples. During *Reflective Breakdowns*, children **pause** by using filler words such as *"um," "uh,"* and *"hmm"*. They **notice** their artifact and label it, *"a forest" "elephant"*, or *"rain"*. To start storytelling, many children begin by noticing the elements of their artifacts, *"There was trees. There was animals. There was ground. There was, um, the sky."* Through noticing, they share memories too: *"Um, I felled at school."* Children often share **uncertainty**, *"Um. I. I don't know"* or *"Um I don't, haven't, I haven't decided yet."* And sometimes children exhibit surprise, *"Huh? That's weird."* Or, children express confusion: *"Um, I think I kind of misunderstanded."*

When detecting **conflict**, children talk about *"fighting," "chasing,"* and *"death."* In one child's story, *"They push the bad guy in,*

Table 2: Description of Each Reflective Process in the Dimension of Breakdown

	Dimension	Process	Description
1	**Breakdown**	Pausing	*We interrupt our momentum with a pause, halt, breakdown, or slowdown.*
		Noticing	*We select a specific situation, phenomena, artifact, or stimulus. We focus our attention and develop our awareness by noticing, recognizing, or labeling.*
		Revisiting	*We iteratively reprocess (or revisit) an encounter, situation, stimulus, or information. We backtrack, perseverate, or repeat ourselves.*
		Uncertainty	*We express surprise, confusion, doubt, or uncertainty.*
		Conflict	*We detect challenges, problems, differences, or conflict.*

Table 3: Description of Each Reflection Process in the Dimension of Inquiry

	Dimension	Process	Description
2	**Inquiry**	Gathering Data	*We gather data by offering prior knowledge or noticing new aspects and contexts.*
		Connecting Data	*We build connections by combining elements, sequencing, or integrating information.*
		Thinking it Through	*We actively weigh considerations by evaluating options, affordances, or consequences.*
		Experimentation	*We actively inquire by experimenting, manipulating, or asking questions.*

Table 4: Description of Each Reflective Process in the Dimension of Transformation

	Dimension	Process	Description
3	**Transformation**	Explanations	*We demonstrate a greater understanding of a current situation. We provide an explanation or articulate their reasoning*
		Ideas & Solutions	*With deeper understanding, we discover a solution, share a transformed perspective, or offer a new idea.*
		Decisions & Directions	*We demonstrate flexibility by adapting, making adjustments, changing our situation, choosing a new direction, or making a decision.*
		Resolution	*We demonstrate a resolution by reaching a conclusion, describing an outcome, summarizing, or synthesizing.*

Table 5: Measuring the Dimensions of Reflection in Children's 260 Total Responses to a Robot

Total Responses	Non-Reflective Responses	Reflective Breakdown	Reflective Inquiry	Reflective Transformation
260 (100%)	29 (11.15%)	69 (26.54%)	119 (45.77%)	43 (16.54%)

um, the bad guy's trying to run away." Here, children share challenging personal experiences: *"I goed to school and my friends were not listening and Mr. [Name] said he didn't love me."* Children use qualifiers — such as *"too much"* — to indicate conflict within their stories, *"There was water, too much, in the soil."* Children also share their challenges: *"I'm getting a little tired here. Well people say that sometimes."* Finally, children engage in reflective breakdown by iteratively **revisiting** their experiences: *"And then after that, when [the] timer went up, it was right now. And, and then, the story was right now. So it was the story was right now and right now."* Here, repetitive phrases are indicators of iterative reprocessing.

4.2.2 Reflective Inquiry: Transcript Examples. During *"Reflective Inquiry"*, children **gather data** by building on their uncertainty with prior knowledge: *"Well, I don't really know. Because I, because I, cause I don't really make names of stories and this is really my first time making up a story."* Here, children explore their knowledge by sharing about themselves, *"After I was in kindergarten the other day yesterday it was my birthday."* They also gather data by building on their previous statements, *"Um, I felled at school. I felled at school and then I got back up."* When **connecting data**, children sequence together many story elements, *"And then they flew back to their tree and go to the bird nest and eat their worms."* Here, both *"and"* as well as *"and then"* can indicate a reflective connection. Children also connect data by sharing how they create: *"Uh, something else that I make on, it's a, I make pencils too. On paper."*

Children **think it through** by building on uncertainty, evaluating themselves, and sharing their thought processes: *"Uh, I don't know. Well. [I] thought of something and I don't even think that, um, I could have made a story of something like good. So, um, I'm, I was also still thinking until I was done and then I forgot now."* And when **experimenting**, children share their creative processes, *"I'm still building because I'm right, because right now I'm in the middle of building a monster truck."* Children also experiment through their characters' actions: *"They tried to get more, um, stuff for their bird nest."* Here, *"tried to,"* *"building,"* and *"making"* can indicate experimentation.

4.2.3 Reflective Transformation: Transcript Examples. During *"Reflective Transformations"*, children build on prior inquiry by **explaining** the motivations behind their characters' actions: *"They woke up in the morning. And then they got out of the bird nest and flied to get some food. Why? Cause they were hungry."* Here, children also explain their own actions, *"And then, um, I tried to fix it and I was still crashing down so I couldn't fix it."* When following prior inquiry, words such as *"because"* and *"so that"* can indicate an explanation: *"The mommy does need to move, um, some eggs. So, cause she wanted some baby birds."* Children also explain their own storytelling patterns, *"I don't know, well, stories are always gonna be short because this is not really like usual. So it's kind of weird what I'm doing."* When making **decisions**, children often use future tense language: *"I'm just gonna like make another creation of my own but I don't, I don't really know how to make a paper cube. So I'm going to ask my dad or mom if they can help me."* This child transforms their uncertainty about one of the robot's questions by planning their future, *"Um, I don't know. I think I'm gonna think a lot, like every day."* Similarly, this child transforms their conflict by planning their next step, *"I kind of destroyed it so I'm starting over."* And this child plans out their next drawing: *"I will make flowers with garden there. And birds flying. And the sun up in the sky and the blue sky in the clouds."*

Finally, children sometimes **resolve** their stories through heroic actions, *"There was the papa troll appeared then and they rescued the horses."* Or, children transform their characters, *"The baby birds growed up into parents, into teenagers. And then they went to, up in the sky."* Children also find resolution by summarizing a difficult memory, *"So cousin passed away and then, and then he died and then he didn't feel good and then he was in heaven."* When thinking aloud, children find resolution by demonstrating an understanding of their own limitations: *"I'm still making a monster truck because, because it's taking a long time for me to build this. Because besides, I don't really know how to make real — like besides, I don't really know how to make stuff, like stuff like monster trucks and like stuff like that. But I build what I can."* Similarly, children resolve conflicts by sharing their wisdom with a robot, *"Because it didn't really work out how I wanted. So I tried again. That's what you're supposed to do. And sometimes it's good to make mistakes you know. Did you know that?"*

5 DISCUSSION

By exploring the ways in which young children reflected during the child-robot interaction, we can better evaluate the impact of reflective design. For example, while we expected that young children would most often engage in reflective breakdown, followed by inquiry and transformation, we found that young children most often expressed inquiry. This may be due to their high levels of playfulness and creativity, whereby they began with an initial element of breakdown (e.g. *noticing* something or *detecting conflict*) then explored it from multiple angles by *connecting* it with both their prior knowledge and new observations. As expected, transformation was the least observed dimension of reflection. Thus, we consider how we might redesign our scaffolds to better support young children in transforming their prior inquiries and breakdowns. For example, how might adding questions to the robot's Q&A that specifically foster the transformative process of creating *explanations* impact the reflective outcomes? Or, how might offering questions that allow children to change the ending of their stories allow them to explore new *directions* and *resolutions*. In this way, each of the 13 reflective processes provides insight into how we might support reflection in practice.

In future work, researchers can use this coding scheme to guide iterative design cycles — first by using the scheme to establish a baseline, and then by experimenting to support specific reflective processes. And throughout, we can use the scheme to measure the impact of our efforts. For example, our team can use this coding scheme to explore the impact of specific robot questions on reflection. We might wonder if "Why?" questions tend to elicit more transformative *explanations*, or if "What?" questions tend to elicit more *noticing*. Similarly, we might consider the impact of question sequence on the development of deeper levels of reflection for different children. Does alternating between question types provide a more supportive scaffold, or does asking similar types of questions repetitively allow a young child to deeply explore an idea before moving on? We can also use this coding scheme to explore what aspects of reflection may be over- or under- represented in our findings, and then iteratively experiment by introducing new robot questions to target a specific reflective process. By examining how reflection unfolds over time for different children, we might also gain an appreciation for the differing approaches that young children playfully take — and build scaffolds that flexibly nurture each unique pattern of approach.

Although this coding scheme was originally designed with young children in mind, the reflective dimensions and reflective processes may be sufficiently flexible and open-ended to encompass the diverse speech and language patterns of older children or even people across their lifetimes. For example, although reflection is essential to the effectiveness of personal informatics systems — e.g., in health, fitness, sleep, or emotion tracking — reflective practices are themselves not reliably supported in many commercial applications [16]. This flexible coding scheme could be used by commercial developers and designers to establish a baseline for the types of reflective processes that their application is currently nurturing, and could serve as a guide for which reflective processes they may need to design new scaffolds for. As they implement new features and update their prototypes, they can then use the coding scheme to measure the impact of their designs.

In addition to the link between reflection and personal informatics, this coding scheme could be used to map the growing connection between metacognition and creativity [80]. Emerging research shows the importance of both idea generation and idea evaluation to creative discovery [66], and this coding scheme could be used to examine the differing ways that reflection may support both of these creative processes [73]. And beyond reflective verbalizations [86], future research might also consider how this coding scheme might be used in creative behaviors and actions. For example, drawing [23, 25], diagramming [24, 60], designing [24, 25, 60], creating [45, 65], and even computer programming [26, 63] can each be inherently reflective experiences, and this coding scheme could be used to characterize how we "reflect-in-action" [70] through a "conversation with the materials" [72]. To explore reflection across a range of creative activities, future work might extend this coding scheme with examples of reflective actions that children (and adults!) employ during artifact construction. In doing so, such work might answer research gaps on the role of metacognition in creative processes [44].

Because children create new ideas by both reflecting on their creative artifacts and sharing their ideas with others [45, 63, 65], future work might benefit by allowing children to play-back their reflective stories in order to further explore them by themselves or with community. In addition to helping them witness their own minds at play, this may spark new ideas for creative iteration. In this way, reflection could provide children with the opportunity to build their creative metacognition [47] — by developing an understanding of their creative strengths and finding new contexts for expressing their creativity. Across interactive systems for creation, reflection, and sharing, we witness the importance of metacognitive reflection in not only supporting young children's development but supporting their sense of discovery too.

6 CONCLUSION

In this work, we contribute a new framework — the *Dimensions of Reflection Coding Scheme* — for examining the impact of designing for reflection in young children. We detail 13 reflective processes occurring within Baumer's three conceptual dimensions of reflection [6], and test the coding scheme with high inter-rater reliability. We apply this coding scheme to 12 child-robot interaction transcripts wherein children ages 4–5 tell stories in response to a robot's Q&A prompting. In doing so, we share rich, illustrative transcript examples across all 3 dimensions and 13 reflective processes of the ways in which young children reflect. We conclude by encouraging interaction designers to explore the use of this coding scheme in measuring the impact of their reflective technologies for young children — and iterating on their designs.

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