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Research paper

Children caring for robots: Expanding computational thinking frameworks to include a technological ethic of care

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ABSTRACT

Computational thinking (CT) is receiving growing attention in educational contexts, where robot coding toys are becoming a widely available means of teaching and learning early computing. As the field of child–computer interaction continues to define what it means for young children to think computationally, much is unknown about the affective dimensions of children's interactions with computers, for example how children care for materials like coding robots and how they establish social responsibility in computational environments. This paper examines these questions in the context of an early childhood coding curriculum designed to support CT in Kindergarten. Children's talk and interactions with robots provide insight into how they were learning to care for and maintain robots when they malfunctioned. Drawing together feminist perspectives on computing, constructionism, and care, we develop a notion of a technological ethic of care and locate this in children's early coding experiences. Through critical discourse analysis, we present two cases where groups of children interacted with each other, their teachers, and a robot called Cubetto, establishing forms of responsibility for technology. We argue that an ethic of care must be part of computational discourses in an era of climate change, where caring for technologies and keeping them in working order is key to sustainable socio-ecological relations.

1. Introduction

Commercially available robot coding toys have become more widely available programming environments for young children (Bers & Horn, 2010; Clarke-Midura, Lee, Shumway, & Hamilton, 2019; Yu & Roque, 2019). Their whimsical construction and tangible interfaces are designed to be engaging, and their ease of use seemingly presents a low barrier of entry for early childhood educators who may have little computer science experience. As robots become regular fixtures in early childhood coding experiences, a growing body of research suggests that young children can develop computational thinking (CT) by engaging with these toys (e.g., Bakala, Gerosa, Hourcade, & Tejera, 2021; Bers, González-González, & Armas-Torres, 2019; Wang, Choi, Benson, Eggleston, & Weber, 2020). However, we know less about what robots teach children, beyond programming skills. For example, how do children respond when robots fail to function as expected? And what responsibilities do children assume for ensuring that coding robots are in working order? This paper explores how forms of responsibility develop between children and robots as they interact in computational environments.

There is a growing recognition within early computing education that authentic programming experiences involve more than reproducing computational representations and artifacts (Sengupta, Dickes, & Voss Farris, 2021). The fields of computing and computer science education have been taking an affective turn, where coding involves children developing relationships with and within computational contexts (Bers et al., 2019; Phillips & Killian Lund, 2019); however, there is scant research on the social or emotional dimensions of early childhood computing. Whereas much of mainstream computing education privileges abstract reasoning, an emerging computational care ethic centers relational epistemologies and affective experiences. A recent review of child–robot relationship formation found that within studies of child–robot interactional styles, the question of how children respond affectively to robots demands more systematic research (van Straten, Peter, & Kühne, 2020). A related review of tangible coding robots cited a need for further study of social contexts involved in designs of CT learning experiences (Bakala et al., 2021). This paper responds to these calls by examining how

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children learn to relate to and care for robots as they learn to code them.

Often the relationships valued within the reframing of coding-as-caring are predicated on a social order whereby *human* relationships are strengthened by learning to code or think computationally (e.g., Phillips & Killian Lund, 2019). Another approach takes technologies such as robots as potential "relational artifacts" and then asks what forms of interactions develop during robot–child interactions (e.g., Turkle, Breazeal, Scasselati, & Dasté, 2004); typically, this approach is in service of *individual* children's social development (e.g., Laurie, Manches, & Fletcher-Watson, 2021). A third form of relating to computers positions young children as objects *of* care that must be protected against the potential risks of computer-mediated interactions in childhood (e.g., Pea et al., 2012). All three approaches are important because they disrupt prevailing notions of programming as abstract, formal, and logical and characterize child–computer interaction as inherently social and affective (Turkle & Papert, 1992). What is missing from these studies is a consideration for the ways in which an ethic of caring *for machines* develops through programming them. Addressing this has the potential to bridge these various approaches.

The present study examined the ways children interacted socially with robot coding toys while learning to code and analyzed how young children develop an ethic of care in the context of an early childhood CT curriculum. We found that despite the fact that we did not design for it – and in spite of teachers' attempts to maintain focus on the coding tasks – children shared many ideas, questions, imaginings, stories, and jokes about robots. What we came to call "robot talk" (i.e. things children said to or about robots) overflowed the frame of designed coding activities, providing insight into children's emerging social relations to robots and to technology more broadly. The talk and interactions that involved the robots point to educational possibilities of introducing technologies to children at an early age.

In what follows, we focus on one dimension of these interactions that we believe represents such potential: caring. First, we situate our study in frameworks for early childhood computing and computational thinking and bring these into conversation with perspectives on robot–child interaction based in a feminist ethic of care, which foregrounds relational epistemologies and care thinking (Puig de la Bellacasa, 2017). Then we present two cases where children and their teachers came into caring relations with a coding robot to demonstrate how they were developing a technological ethic of care in their computational context. We argue that centering care in child–computer interactions pushes computational thinking frameworks to incorporate broader socio-ecological contexts for early computing.

The contributions of the present study are three-fold. First, this paper contributes to a growing body of work in *early computing education* research that is increasingly focused on children's computational thinking (Angeli & Giannakos, 2020). By analyzing children's natural conversations with and about robots during coding lessons, we aim to build with others studying broader contexts for CT (e.g., Bers, 2020). Second, our analysis engages a tradition of research on children's *social interactions* while using computers, specifically in the context of child–robot interactions (e.g., de Jong, Kühne, Peter, van Straten, & Barco, 2020; Peter, Kühne, & Barco, 2021). Although the robot coding toys children used in our study were not designed to be social, children's treatment of them as not only biological, but potentially human-like and social builds on extant child–robot studies (van Duuren & Scaife, 1996; van Straten, Peter, Kühne, & Barco, 2020). Third, we bring a *feminist perspective* to children's interactions with computational tools. We do so, not so much to explicitly address persistent gender differences in computing (Angeli & Valanides, 2020; Keune, Peppler, & Wohlwend, 2019) or in caring (Puig de la Bellacasa, 2017), but rather because feminist epistemologies offer tools for critically examining canonical approaches to computing that tend to value abstraction but may neglect how computers are vehicles for children's concrete learning, conversations, and care (Turkle & Papert, 1992).

2. Framing early childhood computing through a feminist ethic of care

The theoretical strands that informed analysis in the present study were likewise three-fold. First, we drew on expansive frameworks for computational thinking, focusing on those that emphasize relational and ecological dimensions of computing. Second, we frame our study through a strand of constructionist thought that we trace back to Papert and Turkle's collaborative work on epistemological pluralism (Turkle & Papert, 1992) and relational artifacts (Turkle et al., 2004). Third, and building with some of Turkle's ideas, we center feminist perspectives on technology, particularly those that theorize care as an orienting ethic for interacting with computers. Together, these framing perspectives provide a lens for characterizing children's social interactions with educational coding robots.

2.1. Expansive frameworks for early childhood CT

There is a growing interest in developing young children's computational thinking (CT), that is, their ability to solve problems both with and without computers (Bers et al., 2019; Shumway, Welch, Kozlowski, Clarke-Midura, & Lee, 2021; Wang et al., 2020). Some researchers have incorporated affective (e.g., Bers et al., 2019; DeLiema et al., 2020) or aesthetic (e.g., Brady, Gresalfi, Steinberg, & Knowe, 2020; Sengupta et al., 2021) aspects of computing and considered contexts for CT beyond classroom teaching and learning. These expansive framings of computational thinking begin to situate technologies used for CT learning in broader ecologies of their development and use. For example, Bers' (Bers et al., 2019) framework for Positive Technology Development (PTD) incorporates developing and sustaining relationships with learning to use coding technologies like robots. As another example, Rudakoff and Khan (2019) developed a framework for thinking about the significance of CT across socio-ecological scales. In addition to components like *computational identities* and *computational experiences*, they suggest that *computational sustainabilities* and *computational ecologies* are also relevant for learning.

A recognition that developing CT in early childhood entails thinking across scales of child–computer interaction, from the individual or ontogenetic to the ecological or socio-historical, then raises the question of how young children enact forms of caring and responsibility with computers. Expansive frameworks for child–computer interaction involve re-imagining metaphors of computing (Angeli & Giannakos, 2020), and resituating computational thinking or computational objects in terms of children's ways of relating to the world through affective, embodied experiences. Sengupta and colleagues (Sengupta et al., 2021) wrote of centering relational work of computing education:

> It is then a celebration of femininity over masculinity, of caring and togetherness over solipsism and individualism, of heterogeneity over homogeneity... It is the story of how computational objects become meaningful, but not merely personally – to the self and to the others who care for and with each other, and in the embodied and material worlds – without necessarily being folded onto the computational artifact" (p. 187).

2.2. Coding robots as relational artifacts

This focus on relations with rather than productions of computational artifacts lies at the heart of constructionism, a theory of learning and a theory of computing informed by feminist epistemology (Ames, 2018; Kafai et al., 2019; Lachney & Foster, 2020; Sengupta et al., 2021; Turkle & Papert, 1992). Whereas a Logo-centric version of the history of Seymour Papert's robot turtles and their descendants could be used to situate this study of robot coding toys (McNerney, 2004), we instead draw on descriptive studies of social robots to understand how children were relating to robot coding toys as they engaged with these tangible programming tools. Reframing in this way represents a theoretical shift from the formal and logical to the social and relational aspects of computing (Turkle et al., 2004; Turkle & Papert, 1992). It also reflects Papert's (Papert, 1980) desire to "develop a new perspective for education research focused on creating the conditions under which intellectual models will take root", a perspective profoundly rooted in his own childhood experiences of developing "*feeling*, *love*, as well as understanding in my relationship with gears" [emphasis in original] (p. xx).

Papert's affective focus was also heavily influenced by his relationship with Sherry Turkle (see Lachney & Foster, 2020), who contributed a feminist lens to early studies of children and technology (eg. Turkle, 2005; Turkle & Papert, 1992). From feminist technology studies, there are numerous illustrative examples of how the social order is made and maintained through people's interactions and conversations with robots (e.g., Alač, Movellan, & Tanaka, 2011; Suchman, 2011; Turkle et al., 2004; Vertesi, 2015), though not necessarily by programming them. Some studies of children learning to program robots position child–child interactions as the outcome of social robotics (e.g., Laurie et al., 2021) but exclude robots themselves as social actors or "relational objects" (Turkle et al., 2004). What is missing is consideration of the sociotechnical ordering that takes place when children program robots that includes the technical object as a social actor worthy of care.

2.3. Feminist perspectives on child–computer interaction

An ethic of care exists wherever one finds humans caring for and maintaining their objects and environments (Puig de la Bellacasa, 2017). Technology studies have been a key site for developing a feminist ethic of care (Wajcman, 1991), where a central issue of recent concern has been the human impacts of climate change (Haraway, 2016; Kenney, 2019; Puig de la Bellacasa, 2017). On the one hand, technology development is deeply implicated in the degradation of the environment. On the other, technologies seem to hold a promise to solve some of our biggest social and environmental challenges. There has been growing recognition of how children themselves care for and within more-than-human worlds (Hodgins, 2015; Pacini-Ketchabaw, Taylor, Blaise, & de Finney, 2015). With a few exceptions (see Laurie et al., 2021), we know less about how children care for and with technologies like robots, tools that both promise to improve socio-ecological conditions and are objects that people must keep in working order.

Taking a feminist epistemological perspective within early computing education does not resolve tensions between technology's promise and technological breakdowns, as much as it brings to light the commitments we inherit when we treat technologies uncritically (Benjamin, 2019) or children simply as the *objects* of our care (Cannella, 1997; Gibbons, 2007). A feminist perspective on child–computer interactions takes a relational stance towards technologies used in learning environments and encourages a responsible ethic of care for these same technologies, because keeping things in working order is a key to sustainable learning environments (Silvis, 2019). Keeping technologies in working order is part of developing a "maintenance mindset" (Vinsel & Russell, 2020), and establishing a social order between children and the material world of which they are a part (Denis & Pontille, 2015). In the present study, the stories children spontaneously narrated while learning to program with robots were often not about coding or making things with computers, per se. Instead, children spoke to and of robots, and it is these stories and the social order they speak to that were the focus of our analysis.

3. Methodological approach

The present study was informed by methods of critical discourse analysis (Davies & Harré, 1990) and situational analysis (Clarke, 2005; Pérez & Cannella, 2016), methods grounded in a feminist epistemological approach to learning and social contexts. Critical discourse analysis looks beyond participants' talk to understand the broader social structures (e.g., Sengupta et al., 2021) and materials (e.g., Keune et al., 2019) mediating people's interactions with computers. Narrative examples of children's caring engagement with robots while coding are an important means of establishing new metaphors for computing (Angeli & Giannakos, 2019). As Rogers (Rogers, 2000) noted, the narrative examples that childhood researchers bring to qualitative research offer critical and careful analysis of narrative data that can empirically inform theories of social and cognitive development. Guided by these methodological and theoretical commitments, we asked the following questions that emerged in our study: How do children relate socially to robots while learning to code them? How do children regard robots as subjects or objects of care? How are children establishing responsibility for the technologies they are learning to program?

3.1. Research sites, participants, and robots

These questions emerged in the context of a larger project designed to operationalize early childhood CT in Kindergarten classrooms (Clarke-Midura, Lee, Shumway, & Hamilton, 2021; Clarke-Midura, Silvis, Shumway, Lee, & Kozlowski, 2021; Shumway et al., 2021; Silvis, Lee, Clarke-Midura, Shumway, & Kozlowski, 2020). The analysis in the present study focuses on video recorded observations of 84 children participating in robot coding activities in four classrooms in the Intermountain West region of the US. Children were organized into groups of three to four and worked with one teacher during lessons, where they learned to code using three different robot toys: Cubetto by Primo Toys, Botley by Learning Resources, and BeeBot by TTS. The focal examples in this analysis involve lessons with Cubetto (see Fig. 1).

3.1.1. Cubetto coding activities

Inspired by Montessori materials and LOGO turtle design principles (McNerney, 2004; Montessori, 1967) Cubetto is a cube-shaped wooden robot designed to move forward (F), backward (B), and turn left (L) or right (R) 90 degrees, across a gridded mat (Fig. 1). Several different thematic mats are available, including an "outer space" theme and a "city" theme, as well as the basic mat that comes equipped with the robot, which has grid squares depicting a cactus, a boat, a castle, and a tree, as well as solid color and patterned squares that become the context for Cubetto's adventures. Cubetto is controlled by color-coded tiles or "codes" indicating which direction to move that are inserted into a separate wooden programming board to build algorithms. Some lessons involved supplemental materials we designed, such as affixing masking tape to the grid to delineate planned paths. Lessons were usually staged in a corner of their classroom on the floor, to maximize the space for people and materials.

Fig. 1. Resources used for Cubetto coding activity: (1) teacher; (2) pairs of students; (3) program board; (4) "code" pieces (5); Cubetto robots (x2); (6) activity mat (masking tape added to delineate paths).

3.2. Data sources

All coding lessons were video recorded by a research assistant, who also wrote field notes and design memos during data collection sessions. Each lesson lasted 30 min totaling approximately 36 h of video data across 20 groups. Secondary data included transcripts of children's conversations about robots, which were selected from the larger data set through rounds of iterative qualitative coding and grounded theory development (Charmaz, 2014; Clarke, 2005).

3.3. Overview of analytic approach

We conducted qualitative analysis of video recorded lessons, focusing on children's conversational exchanges about robots as the unit of analysis (e.g. Turkle et al., 2004). Exchanges were as short as a single utterance by a child that received only cursory response from a teacher to longer back-and-forth turns at talk that lasted several minutes and involved topics that were revisited later on in the lesson. Through iterative rounds of open coding and categorizing these exchanges, we developed a grounded theory of how children were caring for robots (Charmaz, 2014). We used theoretical sampling to identify cases for closer analysis, and we present the cases narratively, drawing on children's utterances as evidence of their developing relations with robots as objects of care. Narrative case studies of computational experiences represent an important form of feminist story-telling, where "response-ability" arises through people's conversations about and exchanges with computational tools (Haraway, 2016). Finally, in our discussion, we treated the central concept of care as a "sensitizing concept" (Clarke, 2005, p.77) in order to extend our interpretive analysis beyond children's talk and to situate their caring conversations in broader computational discourses and ecologies.

3.3.1. Content logging and transcribing video

Our data analysis involved several rounds of content logging video and coding transcripts. First, we content logged the video from a portion of the curriculum implementation and conducted open coding for aspects of children's CT, which was the focus of our broader analysis of child–robot interactions (e.g. Alač et al., 2011). Embedded in the children's work of building algorithms, thinking spatially, and decomposing and debugging programs, we noticed a great deal of general talk about robots. We categorized these on-going side-conversations that took place in the context of programming as "robot talk" and subsequently transcribed over 300 unique instances of the children's conversations about and with robots for further analysis. These ranged from a single utterance (i.e. a child's unanswered question about some feature or function of the coding robots) to longer exchanges between children and teachers composed of multiple turns-at-talk.

3.3.2. Line-by-line open coding and categorizing

Using these transcripts, we then conducted a second round of line-by-line open coding using the method of constant comparison, where we looked for patterns in how children talked about (and sometimes *to*) robots (Charmaz, 2014). We identified salient categories such as *robot capabilities* (i.e. children's ideas about what robots could do), *robot mechanisms* (i.e. children exploring how robots work), *robot wishes* (i.e. things children wanted robots to do), *robot stories* (i.e. children imagining a narrative for a robot), and *robot relations* (i.e. how they were treating robots). Dovetailing with some of our collaborating teachers' interest in how robot coding toys engendered students' social affect (i.e. cooperation), and in line with related work by one author on children's development of a technological ethic of care (Silvis, 2019), we decided to focus analysis on the theme of *robot relations*. Looking across instances within this theme, we recognized "caring for a robot" as a form of child–robot relations, which, while not as frequent as other forms, tended to sustain extended rounds of talk in-task. We further refined robot care according to ways of caring, including: giving robots *encouragement and compliments* to reach a goal; governing each other's conduct through *robot rules* so that materials would be well-treated; offering a robot a *helping hand* when the robot went astray; and *maintaining materials* when robots broke down.

3.3.3. Theoretical sampling and identifying cases

Finally, we conducted a third round of analysis of another subset of the data to test our emerging theory of children's caring relations to robots against new data (Charmaz, 2014). Using theoretical sampling, we identified cases where caring was sustained across a lesson or where children seemed particularly invested in taking care of a robot. According to Sengupta and colleagues (Sengupta et al., 2021), whose analysis of youth "voicing code" in computational environments is a model for our own, "in theoretical sampling, the search and selection of relevant data and the theoretical purpose justifying the selection are inextricably interlinked" (p. 71). We focus here on children's *care and maintenance* for broken robots, which hinged on treating robots as more – or less – human. While relatively rare compared with more frequent forms of care, such as compliments and rules, children's ideas about how to repair or maintain robots incorporated how they were understanding their own relations and responsibilities vis-à-vis the more-than-human world of technology. Because we are interested in understanding these forms of responsibility, our selection of cases was guided by whether and how children were engaging in care and maintenance for robots while they learned to program them. We chose the empirical cases below, in part, because they both feature the same robot (Cubetto); this robot's specific characteristics elicited conversation about its status as a machine or living thing which, in turn, engendered care for Cubetto.

4. Summary of findings

In what follows, we describe how children were enacting a computational ethic of care with coding robots as they discussed how to repair or maintain them. In the first case, Layton and his

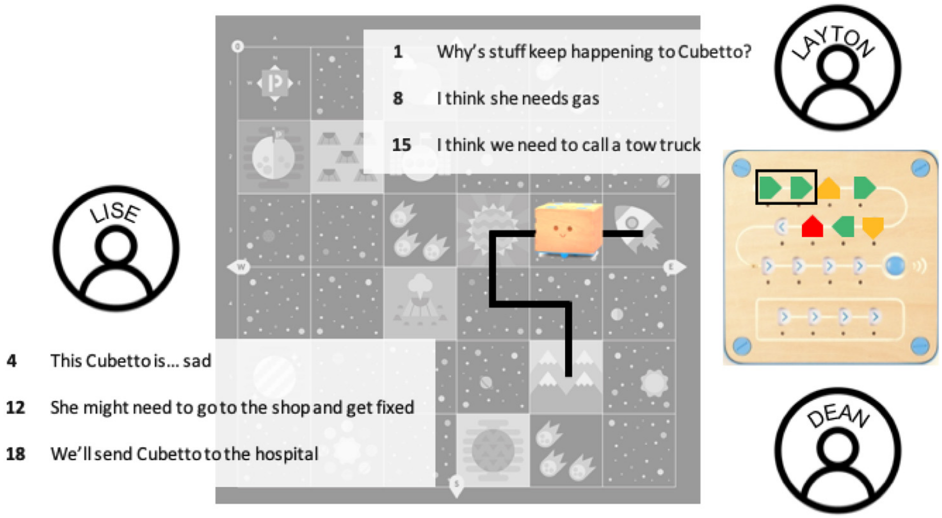

Fig. 2. After planning a path (in black) and programming it (on board), Layton and Ms. Lise discuss a series of remedies for their Cubetto, which is lagging due to a faulty motor. Numbers within the figure refer to line numbers in the transcript.

teacher Ms. Lise engaged in troubleshooting when Cubetto failed to operate properly.[1] Layton treated the robot as a vehicle and developed maintenance strategies that resemble fixing a car or broken-down machine in the repair shop. In the second case, a group of children – Molly, Ivan, David, and Sara – were concerned about exposing Cubetto to "water" as they planned a route that circumvented a blue square on the mat. Their strategies for caring for the robot engaged questions of its biological or technological nature as a basis for caring treatment. In both cases, programming was temporarily deferred as children were occupied by more pressing matters of care and maintenance, and the robot's status as an object worthy of care hung in the balance.

4.1. Machine maintenance or health care: Taking the robot to the shop or the hospital?

While they puzzled through how to program them to move along planned routes, children were frequently puzzled by how robots functioned, or at times, how they failed to function. One such episode occurred when Layton and Dean were programming their Cubetto to travel along a path they had designed that required a sequence of eight codes, including three turns (target program FORWARD, FORWARD, TURN LEFT, FORWARD, TURN LEFT, FORWARD, TURN RIGHT, FORWARD). They tested the initial segment of the code (FORWARD, FORWARD,), but rather than moving forward across two squares of the grid, Cubetto lagged due to a faulty motor, moving at half the usual speed and distance, and causing them to mistakenly believe it required *three* initial forwards (see Fig. 2). Unlike some other coding robots that are designed to move in fluid forward motion, not stopping to execute each individual arrow, Cubetto pauses after each individual movement command in a sequence. Children often complained about Cubetto's slow, plodding pace; however, this Cubetto progressed *unusually* slowly, and the children took notice.

Sensing there was something amiss, and frustrated that what he knew to be the correct sequence was not getting Cubetto to the intermediate goal, Layton asked "Why's stuff keep happening to Cubetto?" (line 1). His question and exasperated tone drew the attention of his teacher Ms. Lise, who had been assisting another pair of children and had not witnessed Cubetto's faulty performance, and then led to the following discussion:

16:46

1 Layton: Why's stuff keep happening to the Cubetto?
2 Ms. Lise: 'Kay, watch... Why is it doing that? (tries to scoot Cubetto forward) I think it's
3 getting stuck right there. (smooths down the tape and picks up the broken Cubetto) This
4 Cubetto is....... sad...
5 Layton: Why's she sad?
6 ML: She's sad because her motors don't want to move at the same time as they're
7 supposed to. Poor Cubetto.

While Ms. Lise attributed human emotions and cognition to the robot (line 4), foreshadowing her proposed treatment, Layton soon developed another perspective on how to address the breakdown, representing a different way of relating to the robot, not as a human but as a machine (Bernstein & Crowley, 2008; Suchman, 2011; van Straten, Peter, Kühne, & Barco, 2020). Returning to programming, Layton was once again hamstrung by Cubetto's lagging motors, and he suggested to his partner that "she needs gas" (lines 8–9). He asserted this several times until Ms. Lise built on his proposal and added that "she might need to go to the shop and get fixed" (line 12). Layton's characterization of the robot as a machine that could require gas provided the grounds for Ms. Lise's expansion of this treatment, towards an eventual repair at "the shop".

19:25

8 Layton: I think she needs gas. (Lise continues to talk to the other group.) I think
9 she needs gas. I think she needs to get more gas.
10 ML: You think she needs some gas?
11 Layton: Yeah
12 ML: She might.. she might need to go to the shop and get fixed. (picks up the working
13 Cubetto) 'Kay, let's see what happens, okay?
14 Dean: We need more gas!
15 Layton: I think... I think we need to call.. a tow truck.
16 ML: You think we need to call a tow truck?
17 Layton: A.. a tow truck for the robot..

As others began to pick up on this approach to a solution (line 14), Layton took the machine metaphor a step further and told

[1] All children's names are pseudonyms. Teachers wished to remain identifiable, so we kept their real names.

the group "we need to call a tow truck" (line 16). Tow trucks and gas are sound solutions for vehicles that break down, signaling how Layton was relating to the robot as a familiar machine that goes in for routine repair and maintenance. In contrast to Layton's mechanical approach to robot repair, his teacher landed on an alternative remedy, circling back to her earlier characterization of the robot as having human feelings, human capabilities, and perhaps human forms of health and wellness. After several minutes and multiple debugging attempts, Ms. Lise took pity on the children and on the robot, acknowledging that "this poor Cubetto needs some help" (line 18) and eventually combined the two pairs of children who collaboratively used the one functioning robot to finish programming. But before they got back to work, Ms. Lise assured Layton that the robot would be just fine because they would "send Cubetto to the hospital".

23:29

18 ML: So this poor Cubetto needs some help. We'll send Cubetto to the hospital.
19 Layton: Are you really sending her to the hospital?
20 ML: No, I'm gonna take it back to the office and fix it...

In slight disbelief, Layton questioned this proposal, and Ms. Lise told him that actually, Cubetto's destination was "the office" where it would get fixed (lines 19–20). Between them, Layton and Ms. Lise characterized the robot as sad, recalcitrant, sick, broken down, and in need of repairs, each of which required different forms of treatment in the shop, the hospital, or the office. These different ways of characterizing the robot – as a machine or as a human – represent different ways of relating to technology, with different consequences for children learning to regard computational tools as subjects or objects of care.

Layton's concern for the robot and his proposed remedy resemble the thinking of professional engineers responsible for maintaining robotic machines. On the current mission to Mars, the rover Perseverance became the subject of similar concern, when its microphone captured alarming, high-pitched scratching noises as the robot explored the surface of the red planet. Dave Gruel, an engineer on the rover team responded that "if I heard these sounds driving my car, I'd pull over and call for a tow" (Browne, 2021). Layton's response to Cubetto reflects this relationship of care and concern, demonstrating how, in order to maintain valued technologies, people attune to robots' mechanical needs and position themselves as responsible for keeping them in working order. Such orientations to the required maintenance of computational tools represent a technological ethic of care children were developing through their interactions with robots.

4.2. Dead in the water: Will the robot drown or sink?

While some children like Layton strategized about how to repair the robot's *mechanism* through their approaches to maintenance, others' caring for robots spoke to a broad interest children have in whether and to what degree robots are *alive*. Living things entail different forms of care than machines, and while a broken-down vehicle might benefit from a trip to the shop, an animate object requires another tactic. Determining robots' biological status is common for children this age, who are learning to relate to computational objects (van Straten, Peter, & Kühne, 2020). And while classifying computers as more-or-less-human draws upon children's emerging understanding of salient features and binary categories (Bernstein & Crowley, 2008), tangible programming environments are complex semiotic environments (Clarke-Midura et al., 2019; Silvis et al., 2020). This complexity demands children think across scales of human interaction and reconcile sometimes contradictory computational identities (Rudakoff & Khan, 2019).

Cubetto's adventure mat was one element of the semiotic ecology in which children were learning to code; the pictures on various mats were useful for creating engaging tasks and for giving children visual markers of start and end points for their programs. In many of the tasks we designed for children to learn to program the robot, they needed to negotiate with each other which path they wanted the robot to take to reach some predetermined destination. There were often multiple possible paths; while children often chose the most efficient path (i.e. the one that utilized the fewest grid squares) or the easiest path (i.e. the one that required the fewest turns), sometimes they used other criteria to decide where Cubetto should (or could) travel.

One group of children was particularly vexed by the possibility that Cubetto might need to travel through the "water" (i.e. across a blue square on the grid that they imagined represented water). While their teacher Ms. Jessica was introducing them to Cubetto's codes, the children excitedly began to devise different paths for the robot, drawing possible routes on the mat (see Fig. 3). Molly and David initially drew paths going over the blue water square (line 2). Quickly reassessing whether it was feasible to have Cubetto go through the water, Molly rejected her initial proposal, stating "it can't or it will drown" (line 3). Implicitly accepting Molly's redaction, Ivan offered that it could just turn and avoid the water (line 4), however Molly was preoccupied with the risks the water posed to the robot. She built upon her initial idea that Cubetto could drown by then suggesting that "it'll die" (line 5).

11:25

1 Ms. Jessica: So, you think that that these codes could help us turn Cubetto different directions?
2 Students: Yeah! (Molly and David draw possible paths on the mat, going over the blue "water" square)
3 Molly: No good. No, it can't go through the water. It can't or it will drown.
4 Ivan: Unless it just turns it and doesn't move (traces another path not over blue squares).
5 Molly: It'll die.

When Molly referred to the robot's death, this prompted various reactions from others in her group and invoked a fundamental question about the status of the robot as machine or biological entity. David disagreed with Molly that Cubetto would die in the water (line 6), and Ms. Jessica deflected the question of death, initiating a less emotionally charged discussion about whether Cubetto could swim or if it floats (line 7). David indicated an interest in pursuing this line of inquiry (line 8), and then Ivan offered a rationale for Cubetto floating, based on his technical assessment of relevant physical principles and the robot's material composition: wood floats, and Cubetto is made of wood, so "technically" the robot floats (line 10). Whereas Ms. Jessica had posed the possibility that the robot could "swim", a biological capability, Ivan countered with a different view of the robot that referenced its nonhuman "technical" features. In contrast to Molly's concern that the robot could die and Ms. Jessica's suggestion that it could swim, Ivan's account remained ambivalent about the robot's biological status: while humans drown and nonhumans sink, both living and nonliving things float.

12:03

6 David: No, it won't.
7 MJ: I don't know... I don't know if Cubetto can swim or if it floats. I don't know.
8 David: Let's see.

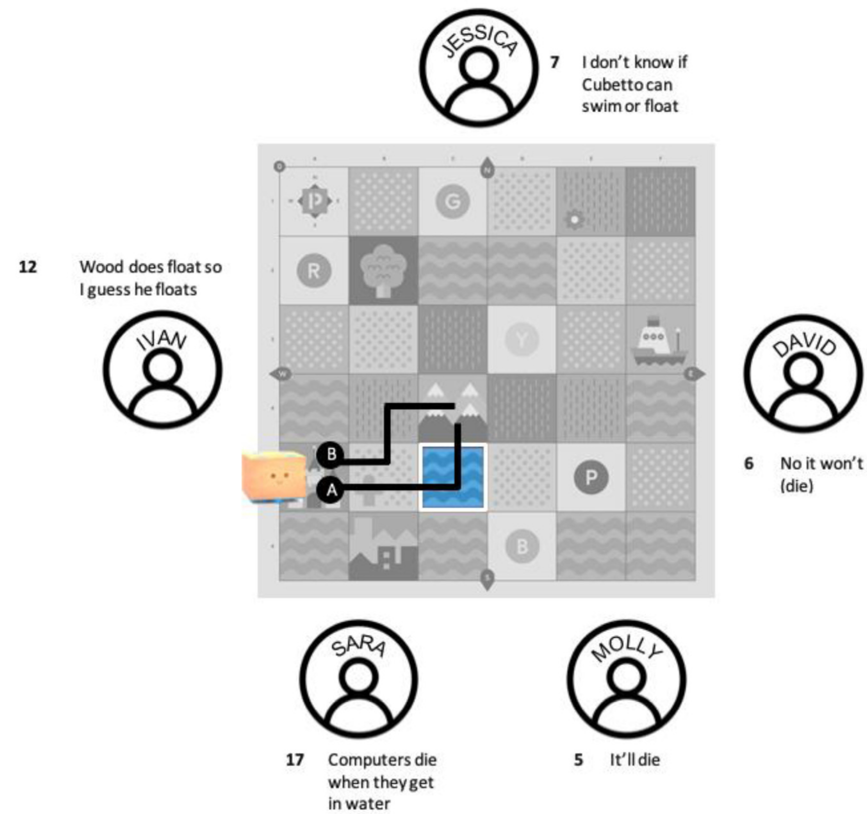

Fig. 3. Ms. Jessica, David, Molly, Sara, and Ivan discuss whether Cubetto will die by traveling through a blue square (route A) but then devise an alternate path (route B). Numbers within the figure refer to line numbers in the transcript.

9 MJ: You want to try it out?
10 Ivan: Well, he's made of wood and technically wood floats (shrugs).
11 MJ: Good point, [Ivan].
12 Ivan: And wood does float so I guess he floats.
13 Molly: He might not be able to float. He might drown!
14 Ivan: Wood does float! But he might have too much weight and then he sinks.

Neither reassured by Ivan's rational approach to deciding Cubetto's fate, nor convinced that the robot could float, Molly reasserted her original concern that "he might drown!" (line 13). Ivan defended his theory about wood floating but then hedged that perhaps Molly's assessment had some merit, acknowledging the possibility that Cubetto would sink because it weighed too much (line 14). This lively debate about whether the robot's aliveness required special care to be taken on the route across the water was temporarily settled when the children decided to test if the robot could go through the water. Ms. Jessica framed testing out their theories as something that programmers often have to do, and the children decided to try out the path through the water. Before they began programming, ultimately abandoning matters of care and concern for matters of coding, Sara, who had been quietly observing her friends' debate about Cubetto floating, made one final bid to settle the matter. After asking permission for a turn at talk, she tentatively added that "computers die when they get in water" (line 17), evoking a new characterization of the robot as a computer, but one that could potentially suffer fatal consequences in water.

14:00

15 Sara: Wait. Can I tell you something?
16 MJ: Go ahead, [Sara]. Start us off
17 Sara: Well... computers die when they get in water.

The children's various ways of treating Cubetto as capable of drowning, sinking, swimming, or floating, evoked a range of views of robots as objects of care that entail different forms of responsibility. Like other children in the classrooms where we conducted coding research – and similar to other studies of children's understanding of robots' biological status (e.g. Bernstein & Crowley, 2008; Turkle, 2005; van Straten, Peter, Kühne, & Barco, 2020) – children used "death" as a distinguishing feature. Rather than a straightforward, rational exercise of dividing up the environment into logical types, more was at stake for the group. In deciding whether the toy had the capacity to die, whether it could sink or float, and to what degree its wooden body contributed to its aliveness, the children were establishing a commitment to care for it. In other words, if traversing the water meant that harm would come to the robot, then they were in a position to determine its fate. For children who are learning to relate to computational objects, establishing the social order requires keeping things in working order and developing a maintenance mindset that orients them to taking care of things.

5. Discussion

We have elaborated an ethic of technological care through two cases where children and their teachers discussed ways to care for robots. While Ms. Lise construed the robot's breakdown largely in human terms, Layton had other ideas. For him, the robot required more mechanical forms of care and maintenance. And while the children in Ms. Jessica's group diverged in their assessment of Cubetto as capable of drowning or sinking, their treatment of the robot's death entailed their own responsibility to care for it, be it computer or living thing. Across the two groups, while children's relation to Cubetto as either human-like or machine-like differed, their treatment of the technology suggests ways in which they regarded it as worthy of care. Following Haraway (Haraway, 2016), we might ask: who is rendered capable of caring and for whom (or for what)?

Both the figures of the human and the robot enacted in these classroom activities broaden what it means to learn, to care, and to learn to care in computational contexts. By engaging with coding robots, children establish and refine categories of aliveness and locate robots somewhere within them. As Turkle (Turkle, 2005) wrote,

> children build their theories of what is alive and what is not alive as they build other theories. They use the things around them: toys, people, technology, the natural environment, a rapidly running stream, the wind that dies down and starts up again… these are objects to think with, to build with (p. 46–47).

And, we would add, these are "objects to care for". To the degree that children's categories, their theories of robot aliveness, and moral beliefs are intertwined, learning to code with robots opens up opportunities to learn to care.

Part of what is at stake in children's questioning robot's capabilities is a tendency many have to divide the world into essential categories: subjects and objects, living and nonliving, biological and mechanical, natural and cultural, as many have shown (e.g., Bang & Marin, 2015; Bernstein & Crowley, 2008; Turkle et al., 2004; van Duuren & Scaife, 1996; van Straten, Peter, Kühne, & Barco, 2020). Humans are both located within logical categories but also embedded within moral and ethical discourses about the operative rules of conduct, care, and concern. Engaging in whether and to what degree a computational object is alive animates children's questions about "whether an ethical discourse is appropriate to it" (Turkle, 2005, p. 60).

Typically, ethical discourses surrounding children in computing take some familiar forms. We can think of these in terms of an ethic of safety, an ethic of kinship, and an ethic of self-reflection. In the first discursive form, the ethics of computing positions children as *objects* of care and concern, for example within discourses of internet security or ongoing skepticism of screen-time (e.g., Livingstone, Haddon, Görzig, & Ólafsson, 2010; Pea et al., 2012; Yip et al., 2019). Within such a discourse, protecting the child is the purpose of developing a moral stance towards computing. A second approach has been to construe children more actively as moral computational agents themselves, but then to render their developing ethic of care in terms of potential benefits for social relationships with *other people* in their lives, such as siblings, peers, parents, or members of their online communities (e.g., Laurie et al., 2021; Phillips & Killian Lund, 2019; Toombs, Bardzell, & Bardzell, 2015). A third tendency is to ask how children's affiliations with computers then alter their moral beliefs about themselves. As Turkle (2005) put it, children use "computer nature for thinking about human nature" (p. 131). This self-reflective orientation posits that ethical computing should account for how our fundamental beliefs about the *figure of the human* are altered – for better or worse – through our relations with computers, algorithms, or automation (e.g., Benjamin, 2019; Suchman, 2011).

Rather than create a fourth discursive form for an ethic of technological care, we would argue that children's caring relations *for* computational objects be incorporated into all three extant discourses (Fig. 4).[2] A technological ethic of care does not stand apart from concern for children, concern for others, or concern for ourselves. Caring for technologies is part and parcel of these ways of relating, and a technological ethic of care must become a central tenant of any ethical discourse of computing. Particularly as children have more and deeper interactions with computers – and as technological development shows no signs of decelerating – children's ethical treatments *of machines* bear on how they will share responsibility for making the future planet a safe and secure place to live, how they will form and strengthen bonds of kinship with other people and the more-than-human world, and how they will understand themselves as part of changing computational and natural ecologies.

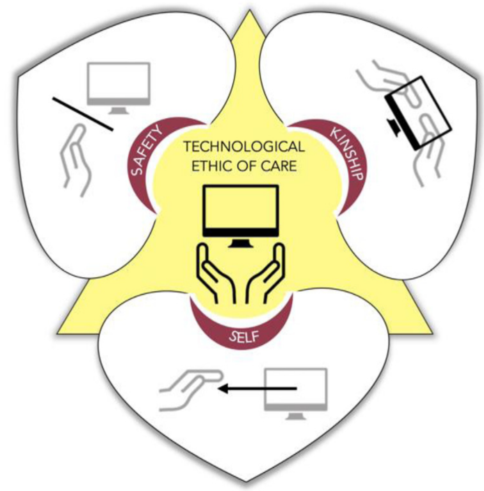

Fig. 4. A technological ethic of care incorporated into discourses of safety, kinship, and self.

6. Conclusions and implications

At this critical juncture for mitigating human-caused climate change, computer science education can play a crucial role. Referring to what they termed a "maintenance mindset", Vinsel and Russell (2020) wrote that "it's difficult to see how… any form of maintenance, can be performed in the absence of care. In turn, it's difficult to see how any technological civilization could survive without it" (p. 43). As Rudakoff and Khan (2019) suggested in expanding their framework for CT, "the webs of connected computational communities or computational ecologies… necessitate thinking in terms of their ethics and sustainability with regard to human and planetary flourishing". Not only are digital technologies comprised of natural resources – like rare earth metals and fossil fuels used in their production – but their obsolescence and disposal produce environmental impacts at timescales that far exceed their use (Gabrys, 2011; Lepawsky, 2018). Recognizing the "histories embedded in digital technologies" represents expansive, critical framing on CT and lends a moral and ethical lens on computing "contextualized within particular personal and political dimensions" (Kafai, Proctor, & Lu, 2019, p. 102). Care and maintenance for would-be neglected technological objects establishes responsible relationships with the tools upon which we depend that is grounded in a "politics of care" (Martin, Myers, & Viseu, 2015). Young children are already taking this responsibility seriously in contexts and ways worthy of closer study.

Early computing education that embraces forms of computational expression such as care and maintenance is what is required in today's complex socio-ecological contexts, where caring is of the essence. Practical applications of expansive CT framings that embrace a technological ethic of care can draw from a heterogeneous collection of extant models. Early childhood

[2] Thanks to Ms. Lise for suggesting our state flower the sego lily as an ecologically evocative model for a technological ethic of care.

approaches that center the more-than-human world help bridge frameworks for child–computer interactions with perspectives on nature-culture relations (e.g., Bang & Marin, 2015; Pacini-Ketchabaw et al., 2015). Montessori education's emphasis on "care of the environment" (Montessori, 1967) and *Te Whariki's* concern for ecological sustainability (Croft, 2017; Duhn, 2012) lend guiding principles and core practices for early educators interested in expanding learning environments to incorporate technological and computational environments. Within early CS education, Bers' (Bers, 2020) PTD framework provides further practical guidance for the applications of care and maintenance for computer technologies in early learning settings.

While the field of child–computer studies is beginning to contextualize computational thinking and child-robot interaction, to incorporate the cultural, social, and affective dimensions of coding, there is still much more we do not know. For example, how do what Bers (Bers, 2020) referred to as children's "choices of conduct and character" relate to their treatment of technologies as worthy of care? In other words, under what conditions do children develop a caring regard for their material tools in computational learning environments? If part of our responsibilities as learning designers and technology designers is to foster children's capacities to be both good digital actors and positive community members, then our curriculum tasks and learning materials ought to include opportunities for children to imagine how technologies like robots can be helpful to humans (e.g., Bers et al., 2019) *and* to practice being helpful to robots. This is important as children interact with computers in a world increasingly populated with robotic or intelligent machines that will require ongoing care and maintenance.

We recognize children's questions about how computers work and how to care for computers as critical entry points for teaching and learning about webs of interconnection that sustain computational ecologies. Based on children's "robot talk", we would encourage learning designers to go one step further and embrace a socio-ecological orientation to students' concerns for technologies. We believe tangible programming is an ideal site to explore what it might look like to incorporate natural ecologies more fully into Rudakoff and Kahn's computational ecologies. From resources like rare earth metals that comprise silicon chips, to human (and increasingly mechanical) labor required to produce a coding robot, to transportation infrastructure that makes computational tools commercially available, all the way to a computer's end-of-life and eventual disposal, *even very young children are capable of making sense of how complex socio-ecological processes upstream make computing possible downstream*. As we have shown, young children are key contributors to developing a computational ethic of care, and they will be key beneficiaries of more socially and ecologically oriented computing education.

7. Selection and participation

We conducted the curriculum activities described in this study in partnership with classroom teachers, who supported our research. After securing approval from district and school administrators, we approached teachers who expressed interest in implementing our curriculum design. In accordance with our Institutional Review Board protocols, we invited parents and guardians of children in the partner classrooms to consent to participate, and we provided them with detailed information about the study. Parents were free to decline consent and were informed that their children would be offered alternative STEM activities during the scheduled research activities if they were not interested in having their children participate. Children were invited to assent and introduced to the data collection methods at the start of the research. During each scheduled classroom visit, they were free to opt out of joining or continuing the curriculum activities at any time.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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