Investigating Separation of Territories and Activity Roles in Children's Collaboration around Tabletops

JULIA WOODWARD, Department of CISE, University of Florida, USA
SHAGHAYEGH ESMAEILI, Department of CISE, University of Florida, USA
AYUSHI JAIN, Department of CISE, University of Florida, USA
JOHN BELL†, Louisiana State University, USA
JAIME RUIZ, Department of CISE, University of Florida, USA
LISA ANTHONY, Department of CISE, University of Florida, USA

Prior work has shown that children exhibit negative collaborative behaviors, such as blocking others' access to objects, when collaborating on interactive tabletop computers. We implemented previous design recommendations, namely separate physical territories and activity roles, which had been recommended to decrease these negative collaborative behaviors. We developed a multi-touch "I-Spy" picture searching application with separate territory partitions and activity roles. We conducted a deep qualitative analysis of how six pairs of children, ages 6 to 10, interacted with the application. Our analysis revealed that the collaboration styles differed for each pair, both in regards to the interaction with the task and with each other. Several pairs exhibited negative physical and verbal collaborative behaviors, such as nudging each other out of the way. Based on our analysis, we suggest that it is important for a collaborative task to offer equal opportunities for interaction, but it may not be necessary to strive for complete equity of collaboration. We examine the applicability of prior design guidelines and suggest open questions for future research to inform the design of tabletop applications to support collaboration for children.

CCS Concepts: • **Human-centered computing → Empirical studies in collaborative and social computing**

KEYWORDS

Interactive tabletops; children; collaboration; territory; activity role; qualitative analysis

ACM Reference format:

Julia Woodward, Shaghayegh Esmaeili, Ayushi Jain, John Bell, Jaime Ruiz, and Lisa Anthony. 2018. Investigating Separation of Territories and Activity Roles in Children's Collaboration around Tabletops. In *Proceedings of the ACM on Human-Computer Interaction,* Vol. 2, CSCW, Article 185 (November 2018). ACM, New York, NY. 21 pages. https://doi.org/10.1145/3274454

1 INTRODUCTION

Interactive tabletop computers are predicted to enter widespread mainstream adoption in the next decade [17]. Tabletop computers are already being integrated into classrooms for educational purposes and collaborative learning [5]. Previous research has found that using

† Work conducted while a summer intern at the University of Florida.

This is work is supported by the National Science Foundation, under grants IIS-1218395 / IIS-1433228 and IIS-1552598.

Author's addresses: J. Woodward, S. Esmaeili, A. Jain, J. Ruiz, and L. Anthony, Department of CISE, University of Florida, Gainesville, FL, 32611, USA; J. Bell, Louisiana State University, Shreveport, LA, 71115, USA; julia.woodward@ufl.edu, jaime.ruiz@ufl.edu, lanthony@cise.ufl.edu;

tabletop computers in collaborative group settings can aid in equity of participation [26] and learning [20]. However, in prior work that has examined children's collaborative behaviors when interacting together on tabletop computers in museum [2,9] and classroom [6,24] contexts, it was found that children exhibit frequent negative collaborative behaviors, such as blocking others' access to objects, fighting for control, and off-task discussion [6,8,14,18,23], which can distract the children from their learning task.

Previous work on collaboration has suggested design guidelines to support more positive collaborative behaviors, such as personal territories [29], enforced collaboration [1,3], enforced turn-taking [21], and independent roles [31]. For example, Scott et al. [28] observed that university students, when collaborating on a physical tabletop, naturally partitioned the tabletop into different territories. They observed that these personal territories facilitated monitoring of other group members, clarified roles, and aided in protection of work. However, most of these design guidelines have not been evaluated with interactive tabletop computers. It is necessary to apply and examine existing design guidelines in order to analyze their applicability in different contexts and determine their relevance, significance, and limitations. In this paper, we present a study of a multi-touch picture searching application we developed in which we implemented two design recommendations, *separate physical territory partitions* [29] and *activity roles* [31], to examine whether children's negative collaborative behaviors would still occur.

We observed and video recorded six pairs of children, ages 6 to 10, interacting with our application, and conducted a rich qualitative analysis of how the children collaborated together. Children in this age range are of particular interest because of the rapid cognitive development that occurs during this period [19]. According to Piaget's model [19], the children in this age range span the preoperational stage (ages 6 and 7) and the concrete operational stage (ages 8 to 10). During the shift between these two stages, children begin to develop logical thought and decrease in egocentrism (e.g., inability to understand that other people have unique perspectives). We decided to focus on this age range to observe how technology-enabled collaborative behaviors may change and develop between ages and stages of cognitive development. We developed a coding scheme of collaborative behaviors based on prior work and used it to qualitatively code our video data.

Our analysis revealed that the collaboration styles differed for each pair, both in regards to the interaction with the task and with each other. Several pairs exhibited negative physical and verbal collaborative behaviors, such as nudging each other out of the way and criticizing each other. One pair in particular did not work well together: the children were both fighting for dominance and constantly argued. Yet even the pairs with severe negative collaborative behaviors had instances of positive collaboration (e.g., sharing and explaining). Perhaps counter-intuitively, we observed that pairs exhibiting an inequitable dominant-submissive collaboration style still had many successful instances of collaboration (e.g., planning and explaining), and did not necessarily exhibit negative collaborative behaviors (e.g., nudging and blocking).

Based on our analysis, we suggest that it is important for a collaborative task to offer equal opportunities for interaction *with the task*, but it may not be necessary to strive for complete equity of *collaboration*. In our application design, the two separate territories were imbalanced in size as well as interaction ability, inspired by previous collaborative role paradigms such as the Navigator-Driver [22], in which one person has control and directly interacts with the technology (e.g., driver) and the other person guides the interaction verbally (e.g., navigator). We believe this inequality led the children to tend to interact with the area with the most interaction capability more often, regardless of the activity role they were actually assigned. We observed an interplay between verbal and gestural dominance in each of the pairs; in each pair, one of the children tended to dominate verbally, gesturally (e.g., interacting with the tabletop), or both. The pairs with one child who dominated verbally and gesturally had frequent instances of positive collaboration, such as sharing ideas, and did not regularly exhibit negative behaviors (e.g., nudging, arguing), even though there was an imbalance in equity of collaboration.

Our contributions to the CSCW community include: (1) a deep qualitative analysis of collaborative behaviors in a study with six pairs of children, (2) an evaluation of how successful previous design recommendations for collaborative interaction (e.g., separate territories and activity roles) are in a real system, and (3) identification of open questions for future research in this space. This work will inform the design of tabletop applications to support collaboration for children, in learning applications or in general.

2 RELATED WORK

We focus our review of prior work on three categories: (1) children's collaborative behaviors on tabletop computers, (2) benefits of shared physical space and territories when collaborating around a tabletop, and (3) design recommendations for children's tabletop activities, including previous recommendations from the CSCW community.

2.1 Children's Tabletop Collaboration

Prior work has examined children's collaborative behaviors when interacting together on tabletop computers [8,12,14,18,23,24,30], as well as how the software capabilities and physical characteristics of the tabletop influence how children collaborate [12,23]. Harris et al. [12] observed 45 children, in 15 triads (ages 7 to 10), collaborating on a classroom seating plan task on an interactive tabletop in two conditions: single-touch and multi-touch. They found that children talk more about the task when using a multi-touch tabletop, while there was more turn-taking discussion in the single-touch condition. Rick et al. [24] completed a deep analysis of three pairs of children (ages 8 and 9) working together on pattern and fraction tasks on a multi-touch tabletop. While the three pairs collaborated effectively, Rick et al. found that each pair were distinct in their behaviors, and they therefore suggested that it is important to consider each group's own dynamics when designing for this context.

Children sometimes have trouble collaborating effectively [10,13] and have been shown to frequently exhibit negative collaborative behaviors when using a tabletop computer, such as fighting for control, blocking, and off-task discussion [6,8,14,18,23]. Marshall et al. [14] compared children's collaborative behaviors when using a paper prototype versus an interactive tabletop computer while designing a classroom seating plan. They examined 10 groups of three children, ages 7 and 8, with each group collaborating with either the paper prototype or the interactive tabletop. The children competed for design materials in the tabletop condition more frequently, by blocking access, moving the materials out of the other children's reach, or physically moving the other children away. Olson et al. [18] completed a case study of children's collaborative behaviors around a desktop computer, multi-touch tabletop, and a physical board game. They observed a group of four children (ages 8 to 11) collaborating in each condition and found that the children exhibited territorial control and conflict over interface elements (e.g., the toolbar) when using the tabletop. They redesigned their interface to include a tangible object to control the toolbar that resulted in less conflict. Fleck et al. [8] completed a case study of 27 children, assembled into nine groups (ages 7 to 9), collaborating on an activity to arrange desks in a classroom on a multi-touch tabletop. The children frequently undid each other's work, which led to fighting for control. However, Fleck et al. argued that, when these negative behaviors are in tandem with verbal discussion, it can sometimes lead to effective collaboration. An example they give is a case in which one child was blocking access to an object, which led another child to explain proposed actions for the object more thoroughly.

Prior work has provided recommendations to support children's effective collaboration (e.g., separate territories). However, these recommendations have not been evaluated in a real system. Therefore, we implemented separate partition territories and activity roles to see whether negative collaborative behaviors would still occur.

2.2 Shared Physical Space and Territories on Tabletop Computers

Previous work in tabletop collaboration has shown that both children and adults take physical responsibility for the tabletop area that is closest to them [18,23,28]. Rick et al. [23] investigated 15 children (six groups of two or three children), ages 7 to 9, performing a shared-space task using a multi-touch tabletop. They found that the children used the entire tabletop surface but mainly took responsibility for the space closest to them, and touched the tabletop more in the multi-touch condition. Scott et al. [28] conducted an observational study of three groups of university students (using a non-interactive tabletop) and noticed that the participants used three types of territories: *personal*, *group*, and *storage* territories (e.g., storing task resources). They observed that personal territories facilitated monitoring of other group members, and partitions clarified roles and facilitated protection of work. Scott et al. also contributed design recommendations such as providing transparency of action. Our design facilitates the use of personal territories through *partitions* and the concept of *activity roles*.

Shared physical space has also been shown to positively influence collaboration [15,30]. Scott et al. [30] observed 24 children in groups of two (ages 11 to 13) playing a collaborative mathematical computer game in three conditions: shared, side-by-side, and separated. The shared physical space, the ability to utilize gestures, and the physical proximity of the children all increased collaboration. The children rated the shared condition as the easiest because they could communicate more effectively, but rated the separated condition as the most fun because it was more challenging since they could not see each other. We designed our application to run on a multi-touch tabletop that resulted in close proximity, while capitalizing on the idea of separated conditions through separate partitions and activity roles. We wanted to understand whether the negative collaborative behaviors would still occur when children interacted in this paradigm.

2.3 Design Recommendations for Children's Tabletop Activities

Several prior studies have suggested design guidelines for creating collaborative activities for children, such as enforced turn-taking [21], enforced collaboration [1], and territoriality [11]. Goh et al. [11] provided guidelines such as using physical space and territoriality, as well as co-touch points (e.g., points that must be touched simultaneously) that were effective in creating a collaborative game for children. Other work has looked at enforcing specific collaborative behaviors in children [1,3,21]. Battocchi et al. [1] designed a Collaborative Puzzle Game (CPG) for a multi-touch tabletop to foster collaboration in children with Autism. The CPG features enforced collaboration (e.g., the puzzle pieces had to be touched and dragged simultaneously by two players), which was shown to have a positive effect on collaboration. Cappelletti et al. [3] designed StoryTable, a cooperative storytelling activity for children on a multi-touch tabletop. The goal was to enforce collaboration by forcing the children to perform crucial tasks together through multi-user actions (e.g., multi-user touches).

Fig. 1. Screenshot of our I-Spy application showing the pool scene. I-Spy images courtesy of the original artist, Maria Neradova.

While this prior work was effective in examining these specific design suggestions, it might not be beneficial to focus on equity of participation or enforced turn-taking depending on group dynamics [24]. Also, none of the papers that examined specific design recommendations provided a rich analysis of the individual groups, which could have caused distinct collaborative behaviors to be overlooked. The CSCW community has recommended territoriality [28] and enforced turn-taking [21] for collaborative tabletop applications, but the recommendations have not been evaluated to examine whether they decrease children's negative collaborative behaviors. By separating roles, we take advantage of shared physical space and territoriality, while trying to encourage collaboration without the rigidness of enforced turn-taking.

3 COLLABORATIVE "I-SPY" PICTURE SEARCHING APPLICATION

For our study, we created an application inspired by the childhood game "I-Spy", in which one player looks around the physical environment and provides verbal clues: "I spy (with my little eye) something blue.", and the other players have to try to guess what the object is. In our application, the children had to locate missing items in an image. The application had two distinct areas: (1) the *clue* area on the left side of the screen that held close-ups of the image with an item missing, and (2) the *big picture* area on the right side of the screen that held the full image (Fig. 1). The two areas could be interacted with at the same time independently. The children had to match the clue images with the big picture to find what was missing in the clue that was present in the big picture (Fig. 2). The application included two different images, a pool scene and a hotel scene, with different missing items in each image.

3.1 Equipment and Software

We developed the I-Spy application using Open Exhibits [36], a free multi-touch software development platform. Open Exhibits provides an open source SDK, including templates and utilities, that serves as a platform for creating digital museum exhibits and large multi-touch interactive applications. The application was run on a Samsung SUR40 tabletop computer. The resolution was 1920 x 1080 (55 DPI), and the display size was 40 inches, measured diagonally.

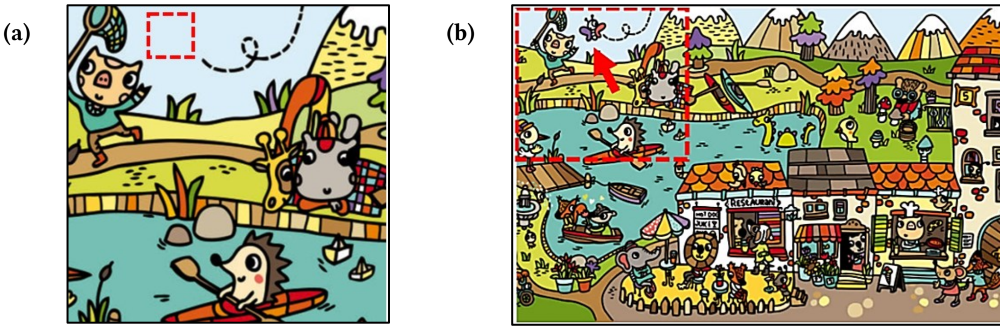

Fig. 2. Example of a missing item in (a) the Clue area compared to (b) the Big Picture area (red outlines provided in paper for clarity). I-Spy images courtesy of Maria Neradova.

3.2 Design

Our I-Spy application interface was split into two main areas: (1) the Clue area and (2) the Big Picture area (Fig. 1). We separated the application interface into two areas in order to support the previous design recommendations we were using, separate territories [29] and activity roles [31].

3.2.1 Clues and Big Picture. The clue area was a scroll pane on the left side of the screen that held 14 separate clue images. Each clue image was a snapshot of a location in the big picture, but an item from the big picture was missing in the clue. For example, Fig. 2a is a clue image and it corresponds to the upper left hand corner of the big picture (Fig. 2b); we added red outlines to the figures in this paper for clarity. In the clue image the butterfly is missing, and therefore is the missing item for that clue. The big picture area was on the right side of the screen and held the complete image. Our application design was inspired by the Navigator-Driver [22] collaborative role paradigm, in which one person mainly interacts with the application (e.g., driver) and the other person guides the interaction verbally (e.g., navigator). A common collaborative learning strategy that utilizes the Navigator-Driver paradigm is pair-programming, which has been shown to help pairs stay on task and increase their sense of shared responsibility [34].

3.2.2 Functionality. The application supported common tabletop gestures, used by both children and adults, such as drag, tap, and swipe [27]. The children could scroll the clue area up and down in order to see all 14 clue images. The complete big picture image did not fit in its entirety on the screen at once; therefore, the children had to pan the big picture image around to find the different locations and items. Once the children found a missing item in the clue, they tapped the item in the big picture and a congratulations message (Fig. 3a) appeared and a

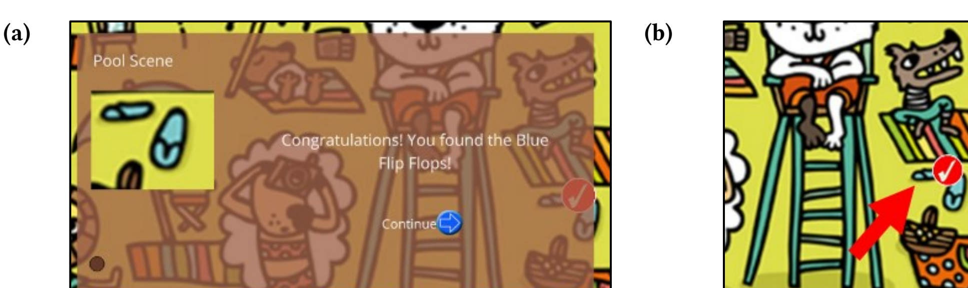

Fig. 3. Example of a found missing item in the Big Picture area (red arrow provided in paper for clarity). (a) Congratulations message. (b) Checkmark on the item once found. I-Spy images courtesy of Maria Neradova.

checkmark was placed on the item (Fig. 3b). The checkmark stayed on the item in the big picture for the rest of the task as a reminder that it had already been found.

4 METHOD

In our study, children collaborated in pairs to find the missing items in the I-Spy application. The children were grouped by age to correspond with their stage of cognitive development according to Piaget's model [19], and there were an equal number of both mixed and same gender groups (Table 1). We did not group siblings or friends together to reduce familiarity. Familiarity has been linked with positive collaboration, because the pair is aware of each other's habits [4]. In our study, we wanted to focus on new collaborations, such as ones that would take place early in a school year versus later in the school year. We assigned each child a role: (1) *clues* – in charge of the clue area and clue images, or (2) *big picture* – in charge of the big picture area and the main image. Each pair collaborated on the two images (e.g., pool scene and hotel scene) provided in the application, switching the activity roles for each image. Therefore, each child experienced both the clues role and the big picture role during the study. We counterbalanced the image order between groups, and we assigned each child a starting role (e.g., clues or big picture). Our protocol was approved by our institutional review board.

4.1 Participants

The children who participated in our study included 12 children, ages 6 to 10 (M = 8.1, SD = 1.4): 2 six-year-olds, 2 seven-year-olds, 3 eight-year-olds, 3 nine-year-olds, and 2 ten-year-olds. Seven children were female, and one child was left handed. All names in this paper are pseudonyms.

4.2 Collaboration Sessions

In the beginning of a session, the children were given time to freely interact with Microsoft Paint [37] to reduce the novelty of interacting with the tabletop, inspired by a similar approach taken by Rust et al. [27]. This also allowed the children to "break the ice" and become more comfortable working with each other before starting the tasks. After several minutes, we instructed the children on the goal of the I-Spy application and gave Fig. 2, without the red outlines, as an example of how to find missing items. We assigned the children an activity role, and they were told that they were in charge of that area. In our verbal instructions to the children, we stated: "[Child 1], you will be in charge of the clues which is on the left side of the game. [Child 2], you will be in charge of the big picture, on the right side of the game, to find the objects based on the clues." We did not intervene if the children did not adhere to their roles, in order to observe natural collaborative behaviors and the effectiveness of the use of roles. After a 10-minute time limit, the children changed to the second image and switched activity roles, regardless of how many missing items they had found. We allowed the children to move to the second image before

Table 1. Pairs of children and their demographics. All names are pseudonyms.

Pair	Genders	Ages (years)
Emma-Olivia	Female-Female	10-10
Ava-Sophia	Female-Female	9-8
Logan-Mason	Male-Male	9-8
Ben-Victoria	Male-Female	9-8
Wyatt-Riley	Male-Female	7-7
Jacob-Zoey	Male-Female	6-6

the time limit if they had found all of the missing items. The children were also given 10 minutes to work on the second image. We video recorded each session with two separate cameras: one from the side, and one above the tabletop pointing down to get a clear view of the screen. The children each earned a small prize after completing each image, as well as a $10 gift card once the study was complete.

4.3 Data Analysis

The first author transcribed the videos from the study sessions by watching top-down videos of each session to record each utterance and gesture (e.g., interacting with the tabletop, pointing to objects). The research team analyzed the transcribed data using qualitative video coding. There was a total of 1 hour and 38 minutes of video data, which contained 1,238 utterances from the children. The qualitative coding was used to identify interactions and actions associated with positive and negative collaborative behaviors. We iteratively developed a coding scheme of interactions associated with collaborative behaviors based on prior work [6,8,25], and added codes that were related to our study (e.g., the activity roles), shown in Table 2. The majority of the codes were drawn directly from Rogat and Linnenbrink-Garcia [25], and we relied on their descriptions and examples for our coding scheme. We also adapted codes from Fleck et al. [8] that focused on physical aspects of collaboration (e.g., knocking hands out of the way), and general codes from Evans et al. [6] (e.g., off-task interactions, software conflicts). The

Table 2. Coding scheme of collaborative behaviors. Citations indicate when these codes were adapted from prior work.

Code Themes	Examples
Social Regulation	
Planning: *planning, grounding what needs to be done, interpreting the directions* [25]	Emma: "*So let's work on the first clue* [pointing to area in big picture]." [code: plan]
Monitoring: *assessing the group's progress* [25]	Logan: "*It is the final one, yeah then we are done* [scrolls to last clue]." [code: monitor]
Positive Socioemotional Interactions	
Active Listening and Respect: *sharing an idea, responding to group member* [25]	Riley: "*There is no mushroom by the thing* [points to clue and then big picture]." [code: share]
Inclusion and Encouraging Participation: *asking questions, using gestures to reference task* [8,25]	Zoey: "*Is this the next clue* [pointing to area in big picture]?" [code: asking idea and using gesture]
Group Cohesion: *using the term "we/us", seeking clarification from group member* [25]	Sophia: "*Ok now we have to, which one are we doing?*" [code: we]
Negative Socioemotional Interactions	
Discouraging Participation: *criticizing or ignoring group member* [25]	Ava: "*Can you keep it like that so I can look?*" (Sophia did not listen) [code: ignore]
Physically Discouraging Participation: *blocking, claiming, knocking group member away* [8]	Ben: "*No, no, no* [knocks Victoria's hand away from the big picture]." [code: knock]
Disrespect: *insulting group member* [25]	Ava: "*So bossy.*" [code: insult]
Interactions (based on our study)	
Roles: *respecting or not respecting assigned role, enforcing roles, pointing to other area*	Riley: "*You gotta click on that screen* [points to big picture]." [code: respecting and enforcing role]
Movement: *moving around the tabletop*	Ava: "*Oh it is the bear guy* (walks around to top of tabletop) [taps bear]." [code: move]
General: *working on task but no discussion, off-task talk, software conflicts* [6]	Ben: [taps continue button in big picture but it doesn't register] [code: software conflict]

collaborative interactions consisted of verbal responses as well as gestures, and were broken down into 4 main themes: *Social Regulation*, *Positive Socioemotional Interactions*, *Negative Socioemotional Interactions*, and *Interactions*. Social Regulation focused on a pair's attempts to regulate their conceptual understanding, for example, planning what they would do next (e.g., Ava: *"Let's do that area* [pointing to first clue]*"*). Positive Socioemotional Interactions referred to interactions that support productive collaboration (e.g., sharing an idea, Logan: "*I have a feeling that it is right over here* [pointing to area in big picture]"), while Negative Socioemotional Interactions dealt with interactions that undermined productive collaboration (e.g., ignoring). Finally, the theme Interactions consisted of codes that were relevant to our specific study, such as whether the pair was respecting their assigned roles (e.g., touching the clue area when assigned to the clue role). We created the codes for Interactions based on our research questions, and then iterated all of the codes after two researchers open-coded a 10% subset of each pair.

We qualitatively coded the video transcriptions along the 11 dimensions in the coding scheme (Table 2). To ensure the code set was reliable, we further refined the codes in an iterative process. In the first phase, two researchers coded two pairs, and a discussion of disagreements and agreements led to refinement of the coding dimensions. We added extra codes to capture interactions that were not represented in the first version of the code set (e.g., pointing to the other area). In the next phase, two researchers independently coded all of the pairs with the refined coding dimensions. We computed inter-rater reliability on the independent data; Cohen's kappa averaged 0.68 (min: 0.19, max: 1.00, SD: 0.27) across the 11 dimensions, corresponding to "substantial" agreement [32]. Finally, the same two researchers met and discussed their independent coding to create a consensus coding for all of the pairs, which we used for analysis. The entire research team examined the frequencies of codes to gain a rough understanding of each pair, and discussed the themes identified in each pair's collaboration.

5 FINDINGS

We analyzed the collaborations of the six pairs of children by examining the consensus coding and transcriptions as a team. We saw that each pair exhibited fairly distinct collaboration styles and behaviors. While the collaboration styles differed among the children, the majority of the pairs were successful in the task and in their collaborations. We first present a description of the collaborative interactions of each of the pairs, roughly organized in order from most positive to most negative collaborative behaviors that we observed. Each description covers both the initial interaction (e.g., first image), and then the second interaction when the children switched activity roles (e.g., second image). Because the tasks were time limited, we provide the number of missing items that each pair found in that time, in order to give context to the scenarios. However, we did not use this number to determine whether the pair had a successful collaboration; instead, this determination was based on the frequency of positive and negative collaborative behaviors we coded, as described above. We define gestures as interactions with the tabletop (e.g., tapping, dragging) as well as referencing objects (e.g., pointing).

5.1 Emma & Olivia: Dominant-Submissive Behavior

Overall, Emma and Olivia (both ten-year-olds) worked well together. However, Emma dominated the interactions both verbally and gesturally: Emma contributed roughly 60% of the pair's verbal utterances and gestures (e.g., *dominant behavior*). Emma was first in charge of the clue area, with Olivia in charge of the big picture. In the beginning, Emma took control of planning, even moving the big picture area against her role, while Olivia was still trying to figure out the task:

Fig. 4. Emma scrolling to the next clue while Olivia moves the big picture to the new clue location. I-Spy images courtesy of Maria Neradova.

Olivia: "*Oh, we are supposed to do these* [pointing to other clue images]?"
Experimenter: "*Yes.*"
Emma: "*Let's look at this* [pointing to area in big picture]."
Emma: [drags big picture to the area]

After several minutes, Olivia seemed to figure out the task goals and started to contribute more. Emma remained dominant throughout the task, even claiming the big picture area (e.g., leaving a finger on the area) while she was supposed to be in charge of clues. Even though Emma was more dominant, the pair exhibited many instances of positive collaboration with each other, such as explaining what they found, suggesting different clues, and sharing their thoughts (Fig. 4.):

Emma: [taps red arrow item in the big picture] *(Note: Red arrow is a missing item)*
Olivia: *"Oh yeah the arrow is not there."*
Emma: [points to the area in the clue image that is missing the red arrow to explain]

The pair did not always adhere to their assigned activity roles, but they continued to share with each other their thoughts on the missing items. The pair found all 14 missing items.

When Emma and Olivia switched roles (e.g., Emma in charge of the big picture), the pair continued to collaborate with each other. The pair also respected their activity roles more, staying within their own areas. Emma continued to claim the big picture area by leaving her hand on the big picture. Since the pair switched roles, Emma was in charge of the big picture area, but continuing to explicitly claim the big picture area shows that she persisted in dominating over the task. In both of the tasks, the pair found all of the missing items and did not exhibit any instances of negative physical collaborative behaviors (e.g., blocking access). Olivia ignored a couple of comments from Emma, but overall the pair collaborated by sharing and explaining their ideas to find the missing items:

Olivia: [scrolls to next clue image]
Emma: [starts dragging big picture to new location to match the clue area]
Olivia: "*Right there, right there* [pointing to area in big picture]."
Emma: "*Oh* [drags big picture to area Olivia pointed at]."

5.2 Wyatt & Riley: Dominant-Submissive Behavior

Wyatt and Riley (both seven-year-olds) collaborated well during both of the tasks. However, Riley was very dominant throughout the task: she contributed roughly 70% of the pair's verbal utterances and 60% of the pair's gestures, while Wyatt was more submissive (e.g., *dominant-submissive behavior*). Riley was first in charge of the clues, with Wyatt in charge of the big picture. Riley frequently grounded the task and plan (e.g., "*Which one are we doing next?*"). The pair did not follow the order of the clue images, so there was a fair amount of discussion about what clue they should do next. Riley constantly shared and thought aloud, and tapped possible items in the big picture even though it went against her assigned activity role. Even when she tapped the items in the big picture, she included Wyatt by explaining how she found the items. In one instance, Riley enforced her activity role by telling Wyatt to interact with the big picture when Wyatt was scrolling through the clue images and ignoring her:

> Wyatt: [scrolling through clue images]
> Riley: "*We are doing that one* [points to clue image]."
> Wyatt: [scrolling through clue images]
> Riley: "*You gotta click on that screen* [points to big picture]."

Yet, right after this interaction Riley tapped a character in the big picture and did not enforce the assigned roles for the rest of the activity. The pair found 12 of the 14 missing items.

When Riley and Wyatt switched roles (e.g., Riley in charge of the big picture), Riley sometimes reached over Wyatt to scroll through the clue images. Both Riley and Wyatt did not often follow their assigned roles, even switching roles right after each other. Later, Wyatt began to speak up more by planning which clue they were on (e.g., "*Second one* [touching second clue image]"). However, Riley continued to be dominant, even suggesting to tap randomly on the big picture (e.g., "*Let's just click anywhere* [tapping randomly on the big picture]". Even though Riley was more dominant verbally and gesturally, she included Wyatt in her thought process, and the pair was able to collaborate and find nine of the 14 missing items.

5.3 Logan & Mason: Divided Dominant Behavior

Generally, Logan (nine-year-old) and Mason (eight-year-old) worked well together. Yet, Logan tended to dominate verbally while Mason dominated gesturally: Logan contributed roughly 80% of the pair's verbal utterances, while Mason supplied around 60% of the pair's gestures (e.g., *divided dominant behavior*). Logan was first in charge of the clues, with Mason in charge of the big picture. While going through the clues, Logan grounded the task (e.g., "*Ok, so this one next* [scrolling down to next clue]"), and Mason dragged the big picture to the new location in response to Logan. Logan was very open and constantly sharing and explaining while Mason tended to be very quiet:

> Logan: "*Oh, right the numbers* [points to numbers on big picture]."
> *(Note: Numbers are a missing item)*
> Logan: "*Look see the numbers aren't right here* [points to area in the clue image]."
> Mason: [taps numbers in big picture]

Although Mason remained verbally quiet, he frequently moved to the next clue image almost impatiently, even though assigned to the big picture. Throughout the activity, Logan seemed a bit frustrated and was not very confident (e.g., *"I don't know, what is going on?"*). The pair found all 14 missing items and Mason silently tapped 10 of them on the big picture.

When Logan and Mason switched roles (e.g., Logan now in charge of the big picture), Mason still tended to move the clue images as well as the big picture. However, Mason started to share and explain more to Logan, especially since Logan continued to get frustrated with the task:

> Mason: *"I see it already."*
> Logan: *"Where?"*
> Mason: *"It is the bucket." (Note: Bucket is a missing item)*
> Logan: *"What?"*
> Mason: [points to bucket in big picture]

Logan: *"What, this thing is bothering me; it is so hard* [taps bucket in big picture]*."*

Even though Logan dominated verbally and Mason dominated gesturally (e.g., moving both the clue images and big picture), the pair still effectively collaborated with each other, such as directing each other back to their role and task:

Logan: [dragging big picture] *(Note: Logan is assigned to clues)*

Mason: [reaches over Logan to motion towards clue area]

Logan: *"Ok, this place* [scrolls down to next clue]*."*

The pair was able to find all of the missing items in the second task as well.

5.4 Jacob & Zoey: Balanced Interaction Behavior

Jacob and Zoey were the youngest pair (both six-year-olds), and our observations indicated that they had a difficult time following the task. The experimenters had to walk the pair through the first clue in order to explain the activity (in addition to the example clue that all pairs were given). Both Zoey and Jacob contributed verbal utterances and gestures roughly evenly (e.g., *balanced interaction behavior*). Jacob was first in charge of the big picture, while Zoey was in charge of the clues. Zoey suggested missing objects and tapped them in the big picture, even though assigned to clues. In the beginning, the pair started to collaborate:

Zoey: *"The lion* [scrolling through clue images]*?" (Note: Lion is not a missing item)*

Zoey: "*Is it right there* [pointing to clue image]*?"*

Jacob: "*Oh, there is the lion* [points to lion in the big picture]."

Zoey: "*That's not it* [pointing to lion in big picture]."

After a while, both Zoey and Jacob started tapping randomly on the screen and did not adhere to their roles or the task. For the first image, Zoey and Jacob only found three missing items.

When Zoey and Jacob switched roles (e.g., Jacob in charge of clues), the experimenters had to remind the pair of the task. Jacob started to claim the big picture and nudge Zoey away from the big picture, even though he was in charge of the clues. Neither Zoey nor Jacob adhered to their roles, and they began to tap the screen randomly, abandoning the task. In the second task, Zoey and Jacob were collaborating less and playing with the tabletop. Even though most of the time they were tapping randomly, there were still some instances of effective collaboration:

Jacob: *"Wait, let's see if there isn't a rock there* [points to clue image]*."*

Jacob: *"We need to see if there is a rock there." (Note: Rock is not a missing item)*

Zoey: [looking for the rock in the big picture]

Jacob: "*We need to go back to the kitty* [dragging big picture around]*."*

Zoey: "*Yep, yep there's a rock* [pointing to rocks in big picture]."

For the second image, Jacob and Zoey found six missing items, mainly from tapping randomly on the big picture. The task was confusing to Zoey and Jacob and they did not follow the directions, indicating that this task may not have been optimal for children of their age.

5.5 Ben & Victoria: Physically Negative and Independent Behavior

Ben (nine-year-old) and Victoria (eight-year-old) had instances of effective collaboration throughout the tasks. However, they mainly worked independently and frequently exhibited negative physical behaviors such as blocking and reaching (e.g., *physically negative and independent*). The pair both contributed gestures roughly equally, but Ben provided about 60% of the pair's verbal utterances. Ben was first in charge of the clues, while Victoria was in charge of the big picture. While interacting, both Ben and Victoria commonly claimed their area (e.g., leaving a finger on their area), as well as actively using gestures to hover around and search for

Fig. 5. Example of Ben claiming the current clue image while also interacting with the big picture. I-Spy images courtesy of Maria Neradova.

items, not always in their assigned areas. For example, Ben commonly held his finger next to the current clue image while reaching over Victoria to use his other hand to interact with the big picture (Fig. 5). Both Victoria and Ben focused on the task; however, there was not a lot of discussion between the two—they mainly worked independently. Victoria sometimes repeated and copied Ben's behavior during the task, by repeating the same sentence or gesture (e.g., tapping the same item in the big picture right after him). The pair found 12 missing items, and although Ben was in charge of the clues, he tapped eight of the missing items in the big picture without an explanation to Victoria. During the task, Victoria seemed to get a bit frustrated that Ben was finding most of the items, stating, "*You're finding literally everything*" to Ben.

When Ben and Victoria switched roles (e.g., Ben in charge of the big picture), Ben became frustrated that Victoria continued to interact with the big picture. Victoria started to move the big picture and Ben remarked, "*I thought I was doing this one...*", but Ben also did not respect the activity roles throughout the task. In a couple of instances, Ben nudged Victoria's hand out of the way of the big picture and reached over Victoria to interact with the clue area. Both Ben and Victoria continued to claim their areas and work independently during the second task; yet, there were still instances of positive collaboration:

> Victoria: "*Oh the triangle* [taps the triangle in the big picture]."
> *(Note: Triangle is not a missing item)*
> Ben: *"Nope, that's not what is missing* [pointing to clue]*."*
> Victoria: *"Oh yeah, oh yeah."*
> Ben: "*It's that* [taps the numbers in the big picture]." *(Note: Numbers are a missing item)*

The pair found 13 of the 14 missing items.

5.6 Ava & Sophia: Verbally Negative and Controlling Behavior

Overall, Ava (nine-year-old) and Sophia (eight-year-old) did not work very well together. Ava tended to be very controlling, while Sophia ignored Ava and did what she wanted (e.g., *verbally negative and controlling*). Ava contributed roughly 60% of the pair's verbal utterances, while Sophia provided roughly 60% of the pair's gestures. Ava was first in charge of the big picture, while Sophia was in charge of the clues. Even in the beginning of the task, Ava was verbally controlling and dominating:

> Ava: "*Let's do that area* [pointing to clue image]."
> Ava: "*That might be a lot easier* [dragging big picture to match clue area]."
> Sophia: [starts to drag big picture with Ava]
> Ava: "*Here we go.*"

Fig. 6. Example of Ava nudging Sophia's hand out of the way of the big picture. I-Spy images courtesy of Maria Neradova.

Ava: *"What is missing from this picture?* [taps clue image]*"*

The pair commonly argued, and Ava constantly told Sophia to stop moving and tapping the big picture. In one instance, Ava told Sophia to "*Stop tapping things*", but Sophia responded by stating, "*It's fun; I am just going to tap everything* [tapping randomly on big picture]." Ava even resorted to nudging Sophia's hand out of the way of the big picture and snapping at Sophia: "*You are taking away my job, it's like you are bothering me 'cause you are moving it around the screen*" (Fig. 6). There was not much positive collaboration; neither of them respected their roles very often, and they consistently argued about the correct clue. However, the arguments about what to do sometimes led Ava or Sophia to explain their reasoning to each other:

Ava: "*Ok wait, I want to do …* [scrolling clue images]."
Sophia: "*Wait.*"
Ava: "*I want to do …*"
Sophia: *"No wait, I want to do …* [scrolling clue images]*."*
Ava: "*We already um.*"
Sophia: "*We can do them in order, it's better.*"
Ava: "*Ok, ok, ok.*"

Also, even with Ava being frustrated with Sophia, Ava provided positive feedback to Sophia (e.g., "*Nice one*") and the pair found 13 of the 14 missing items.

When Ava and Sophia switched roles (e.g., Ava in charge of clue images), the negative collaborative behavior continued. Sophia dragged around the big picture, her assigned role, and Ava yelled at Sophia to "*Stop!*" and nudged Sophia's hand away from the big picture. Sophia continued to ignore Ava, which led Ava to call Sophia "*So bossy*", even though Ava was the one who was trying to control the task. In the second task, the pair found nine of the 14 missing items. Although there was frequent tension, Ava talked aloud and suggested items, and the pair continued to plan and find the missing items together.

6 DISCUSSION

We focus our discussion on (a) evaluating the implemented design recommendations by reviewing the negative collaborative behaviors that occurred in our study, (b) examining the interplay between verbal and gestural dominance in each pair in our study, and (c) reflecting on the distinct pair collaboration styles and behaviors in our study. In each discussion sub-section, we situate our analysis in prior work and suggest open questions for future research on the design of collaborative interactive tabletop applications for children.

6.1 Negative Collaborative Behaviors

We implemented two previous design recommendations, separate physical territories [29] and activity roles [31], into our design to see whether children's negative collaborative behaviors would still occur. Previous work has shown that both children and adults take physical responsibility for the tabletop area that is closest to them [18,23,28], and personal territories help facilitate group self-monitoring [28]. Researchers have investigated applying specific design recommendations such as enforcing turn-taking and multi-user actions to help increase children's tabletop collaboration [1,3,21], but contradicting research has stated that it might not be beneficial to focus on equity of participation depending on group dynamics [24]. We completed a rich analysis of our six pairs, and even though we implemented personal territories with separate partitions and activity roles as recommended by prior work, we still saw many instances of negative physical and verbal collaborative behaviors.

Each of our pairs ranged in the severity and types of negative collaborative behaviors that they exhibited. All of the pairs had occurrences of not adhering to their assigned roles, which sometimes led to reaching over each other, for example. Other pairs exhibited more severe negative collaborative behaviors. Ben and Victoria, who worked together, consistently demonstrated negative physical behaviors, such as claiming areas (e.g., leaving a finger or hand on the area) and physically nudging each other out of the way. Ava and Sophia displayed more negative verbal behaviors, mainly from Ava. Ava was very controlling and Sophia did not listen to her, which led to arguments and Ava calling Sophia "*So bossy*". In several instances, Ava resorted to physically nudging Sophia out of the way of the big picture, even when Sophia was in charge of the big picture. Yet, even the pairs with these severe negative collaborative behaviors exhibited instances of positive collaboration (e.g., sharing, explaining, and positive feedback). Our results echo Fleck et al. [8], in which children's negative collaborative behaviors sometimes led to verbal discussion. In our study, Ava and Sophia constantly argued; however, this sometimes led to the pair explaining their reasoning to each other, improving the quality of their collaboration. We also observed that an otherwise-negative collaborative behavior of reaching over each other was sometimes used to direct each other back to their assigned role, such in the example of Mason reaching towards the clue area to direct Logan back to his assigned area (e.g., clues). Although arguing and reaching over each other are negative behaviors, if they are accompanied by verbal discussion and explanation, they can lead to better group involvement and understanding. Falcão and Price [7] further analyzed the effect of negative peer interference on collaborative knowledge building on a shared tabletop interface. They found that, when conflicts were resolved through pair reflection and discussion, it led to more productive learning interactions. While Fleck et al. [8] and Falcão and Price [7] both observed that pair arguments and reflection can lead to positive collaborative behaviors, they did not provide suggestions for how to support pair discussion. In our analysis, arguments sometimes led our pairs to explain their reasoning to each other. Thus, we suggest that a system could try to aid in the transition from argument to explanation. Explaining is an important aspect of the prediction-observation-explanation inquiry model [33]; this strategy has been applied to curriculum design to expand learners' understanding and generate discussion. Previous work by Yannier et al. [35] has explored designing for explicit support for explanation. They found that providing a prompt for children to make a prediction and explain their reasoning for that prediction in a collaborative learning task led to more active collaboration, and encouraged thinking and learning. However, Yannier et al. [35] only provided a set of specific prompts tailored to the learning task, and did not examine how a system can address real-time negative collaborative behaviors. Therefore, we suggest that future work could examine how systems can intervene during negative collaborative behaviors in real-time, for example, by detecting children's arguments and incorporating relevant prompts to shift arguments into explanations and peer reflection.

We also evaluated the prior design recommendations of separate physical territories [29] and activity roles [31] we implemented by examining how the assigned activity role seemed to affect negative collaborative behaviors. All of the following negative behaviors were exhibited at times by children in either role: criticizing, reaching over each other, knocking each other out of the way, and claiming areas. However, we found that children assigned to the clue role more frequently ignored their assigned role by touching the other area, than did the children assigned to the big picture area. We think this role rejection was more common in the clue role because of the fact that the clues area was smaller in size and afforded less interaction ability than the big picture area (Fig. 1). The clue area only took up about 20% of the screen. The child in charge of the big picture had the ability to tap the missing items, which brought up interactive GUI elements (e.g., the congratulations message and checkmarks), while the child in charge of the clue area could only scroll up and down through the clue images. Though we designed the separate territories and roles in this way based on previous collaborative role paradigms such as the Navigator-Driver [22], it is clear this paradigm does not work well for children in this context. The inequity in the areas' interaction ability and size likely led the children to be more interested in the big picture area. Future work should examine the use of activity roles when the task design is balanced with equal sized territories and equal interactive capability. Also, questions remain about the contexts in which the Navigator-Driver paradigm is beneficial and when it is not. Prior work has shown that pair-programming, which utilizes the Navigator-Driver paradigm, improves student retention [16] and increases the pair's sense of shared responsibility [34]. Pair programming typically only involves one shared view and interaction space. The Navigator-Driver paradigm did not work well in our study, which had one shared view but two separate interaction spaces.

6.2 Interplay Between Verbal and Gestural Dominance

When analyzing the distinct collaborative behaviors of our pairs, we observed an interplay between verbal and gestural dominance. In each pair, one child tended to dominate verbally, gesturally, or both. For example, Emma dominated verbally and gesturally, while Olivia remained submissive. Logan and Mason divided responsibility and worked independently; Logan dominated verbally and Mason dominated gesturally (e.g., controlling both the big picture and clue areas). Ava and Sophia also dominated in separate areas: Ava dominated verbally and Sophia dominated gesturally. Both Logan and Mason, and Ava and Sophia, had frequent occurrences of negative collaborative behaviors, such as nudging each other out of the way and arguing. However, both pairs also had instances of positive collaborative behaviors that included verbal utterances and gestures (e.g., referencing objects and areas through pointing).

Prior design recommendations have focused on enforced collaboration (e.g., multi-user actions) [1,3] and enforced turn-taking [21]. Yet, we think always aiming for equity of participation may not be necessary due to the range of verbal and gestural participation we observed in our pairs of children. Consider Emma and Olivia: Emma dominated verbally and gesturally, but the pair had frequent instances of positive collaboration (e.g., sharing and explaining) without equity of participation. Our analysis contradicts the recommendations of enforced collaboration [1,3] and enforced turn-taking [21], and supports other prior work [24] that has stated it might not be beneficial to focus on equity of participation depending on group dynamics. We suggest that deciding to strive for enforced equity or allowing for the task to remain flexible should be dependent on the context of the task. If the goal of the task is to teach children about equal participation, such as taking turns, then designing the task with enforced turn-taking is a viable option. If the goal of the task is not dependent on equity of participation, then we believe the task could remain flexible for children with different personalities and collaborative behaviors. The task may remain open-ended since some children may feel more comfortable in taking the lead or remaining passive. Rick et al. [24] created a pattern and fraction task, while our study applied an I-Spy task; neither tasks focused on increasing children's collaboration skills, and therefore were successfully able to remain more flexible. Tasks that focus on increasing children's social skills, such as verbal communication with others, may benefit from a more enforced collaboration approach. Future work should examine in what contexts it is appropriate for the task to remain flexible and when to support enforced collaboration.

6.3 Distinct Collaboration Styles and Behaviors

Each of our six pairs exhibited distinct collaboration styles and behaviors. We observed a mix of styles: dominant-submissive behavior (e.g., Emma-Olivia; Wyatt-Riley), divided dominant behavior (e.g., Logan-Mason), balanced interaction behavior (e.g., Jacob-Zoey), physically negative and independent behavior (e.g., Ben-Victoria), and verbally negative and controlling behavior (e.g., Ava-Sophia). Each of the pairs tackled the task differently. We examined whether the assigned activity role affected each child's collaboration style (e.g., dominant, submissive), and found that the behavior occurred regardless of the role. For example, Emma remained dominant throughout the entire session, even when she was in charge of the clues. Therefore, we agree with Rick et al. [24] that collaboration style is more likely to be determined by individual personalities and group dynamics than the task or application design alone.

When examining the children's collaborative behaviors, we saw that different styles led to different negative behaviors. Both Emma and Olivia, and Wyatt and Riley had a dominant-submissive collaboration style. Emma and Riley both dominated verbally and gesturally in their respective pairs; however, there were not many instances of negative collaborative behaviors in these pairs, and both pairs displayed successful instances of collaboration. Thus, we saw that the dominant-submissive collaboration style can be successful when the dominant child includes the submissive child in the task. Even though Emma dominated both verbally and gesturally, she included Olivia through narrations (e.g., saying what she was doing) and explaining how she found a missing item. The joint awareness of the shared physical space of the tabletop [28,30] also enabled positive collaboration in the dominant-submissive relationship, by allowing the submissive child to be included in the task. When both children were trying to dominate the task (e.g., Ava and Sophia) or work independently (e.g., Ben and Victoria), there were clear instances of negative physical and verbal behaviors. Ava and Sophia clashed and argued because Ava was very controlling, while Sophia was independent and did not listen to Ava. The pair fought for dominance of the task, which led to frequent negative collaborative behaviors, such as arguing about where to move the big picture.

By analyzing each of the six pairs, we observed distinct collaboration styles composed of different positive and negative behaviors. Our analysis supports Rick et al.'s [24] argument that it is important to consider each group's own dynamics when designing. Even though we observed negative collaborative behaviors, all of the pairs displayed at least a few instances of positive collaboration (e.g., sharing). However, Rick et al. [24] did not provide explicit ideas of how to design for multiple group dynamics. While our analysis reinforces the idea that it is important to consider group dynamics when designing collaborative tabletop applications, open questions still persist regarding how to design for multiple group dynamics. In our application design, having separate territories and not constraining the pairs to their assigned activity role allowed us to observe distinct collaboration styles. The separate territories let the pairs work independently if they chose to, and not being constrained to the activity roles allowed the pairs to adopt other collaboration styles that worked well for their individual personalities, such as dominant-submissive and dividing responsibilities. Even the pairs that displayed negative collaborative behaviors, such as Ava and Sophia fighting for dominance, had instances of positive collaboration (e.g., explaining). However, open questions remain about what specific collaborative tabletop features and task designs both support and hinder different collaboration styles. For example, future research might examine how constraining children to their assigned role affects collaboration behaviors.

7 LIMITATIONS AND FUTURE WORK

Our work supports the design of collaborative tabletop applications for children. There are some limitations to the scope of our work. First, twelve children (six pairs) participated in our study. Though this number is small, it is similar to previous qualitative work that has deeply examined collaboration with a small number of pairs of participants [18,24,28]. For example, Rick et al. [24] completed a detailed analysis of three pairs of children (ages 8 and 9) working together on a multi-touch tabletop. To increase external validity, our analysis should be expanded in future work with more pairs of children in each age group. An additional factor is that our children did not know each other prior to completing the study, which is more representative of new collaborations than ones that might take place later in the school year. We suggest that future work could also examine pairs of children who know each other to understand how our findings might change as children's collaborations change through familiarity. We also did not screen for compatible personality types when assigning the pairs, which could have affected the interaction dynamics within the pair. Second, we observed that the task was confusing to Jacob and Zoey (both six-year-olds) and they did not follow the directions, indicating that collaborative tasks may not be optimal for children of their age. According to Piaget's model of cognitive development [19], six-year-old children are still in the preoperational stage, and therefore have trouble taking the viewpoint of other people, which is an important attribute in collaboration. The best collaboration seemed to occur with the pair of oldest children: Emma and Olivia, both age 10, who, based on Piaget's model of cognitive development [19], were more likely to be able to understand the perspectives of others. Future work could examine this type of collaborative activity with more children of younger ages to identify how age affects these collaborative behaviors. In our study, we observed that the children sometimes did not adhere to their assigned activity roles, in part due to the imbalance in the interactions afforded by each role. While this has interesting implications for the design of collaborative tasks for children, another possible contributing factor is that we did not explicitly emphasize the importance of collaboration and a team approach in our task instructions. We said the children "will have to work together to find all of the 14 objects that are hidden in the picture," but we did not stress that it did not matter who found the missing items, so both children may have wanted to be the one to tap the item.

8 CONCLUSION

In this paper, we presented a rich qualitative analysis of the collaborative behaviors exhibited by six pairs of children, ages 6 to 10, while they were interacting with our I-Spy picture searching application that implemented two prior design recommendations (e.g., separate territories [29] and activity roles [31]). Our analysis revealed that the collaboration styles differed for each pair, both in regards to the interaction with the task and with each other. We observed an interplay between verbal and gestural dominance in the collaboration styles the pairs exhibited, and some of the pairs exhibited negative physical and verbal behaviors, such as nudging each other and arguing. Based on our analysis, we suggest that it is important for a collaborative task to offer equal opportunities for action/interaction, but it may not be necessary to strive for complete equity of collaboration. We examine the applicability of prior design guidelines and suggest open questions for future research in this space. Our work will inform the future design of tabletop applications to support effective collaboration for children.

ACKNOWLEDGMENTS

This work is partially supported by the National Science Foundation Grant Awards #IIS-1218395/IIS-1433228 and IIS-1552598. Opinions, findings, and conclusions expressed in this paper are those of the authors and do not necessarily reflect these agencies' views. We thank Maria Neradova for allowing us to use her illustrations for our I-Spy application.

REFERENCES

[1] Alberto Battocchi, Fabio Pianesi, Daniel Tomasini, Massimo Zancanaro, Gianluca Esposito, Paola Venuti, Ayelet Ben Sasson, Eynat Gal, and Patrice L. Weiss. 2009. Collaborative Puzzle Game: A Tabletop Interactive Game for Fostering Collaboration in Children with Autism Spectrum Disorders (ASD). In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS '09)*, 197–204. DOI:https://doi.org/10.1145/1731903.1731940

[2] Florian Block, James Hammerman, Michael Horn, Amy Spiegel, Jonathan Christiansen, Brenda Phillips, Judy Diamond, Margaret E. Evans, and Chia Shen. 2015. Fluid Grouping: Quantifying Group Engagement around Interactive Tabletop Exhibits in the Wild. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '15)*, 867–876. DOI:https://doi.org/10.1145/2702123.2702231

[3] Alessandro Cappelletti, Giulia Gelmini, Fabio Pianesi, Franca Rossi, and Massimo Zancanaro. 2004. Enforcing Cooperative Storytelling: First Studies. In *IEEE International Conference on Advanced Learning Technologies (ICALT '04)*, 281–285. DOI:https://doi.org/10.1109/ICALT.2004.1357420

[4] Jonathon N. Cummings and Sara Kiesler. 2008. Who Collaborates Successfully? Prior Experience Reduces Collaboration Barriers in Distributed Interdisciplinary Research. In *Proceedings of the ACM Conference on Computer-Supported Cooperative Work (CSCW' 08)*, 437–446. DOI:https://doi.org/10.1145/1460563.1460633

[5] Jacob Davidsen and Ruben Vanderlinde. 2016. 'You Should Collaborate, Children': A Study of Teachers' Design and Facilitation of Children's Collaboration Around Touchscreens. *Technology Pedagogy Education* 25, 5 (2016), 573–593. DOI:https://doi.org/10.1080/1475939X.2015.1127855

[6] Abigail C. Evans, Jacob O. Wobbrock, and Katie Davis. 2016. Modeling Collaboration Patterns on an Interactive Tabletop in a Classroom Setting. In *Proceedings of the ACM Conference on Computer-Supported Cooperative Work (CSCW '16)*, 858–869. DOI:https://doi.org/10.1145/2818048.2819972

[7] Taciana Pontual Falcão and Sara Price. 2011. Interfering and Resolving: How Tabletop Interaction Facilitates Co-Construction of Argumentative Knowledge. *International Journal of Computer-Supported Collaborative Learning* 6, 4 (2011), 539–559. DOI:https://doi.org/10.1007/s11412-010-9101-9

[8] Rowanne Fleck, Yvonne Rogers, Nicola Yuill, Paul Marshall, Amanda Carr, Jochen Rick, and Victoria Bonnett. 2009. Actions Speak Loudly With Words: Unpacking Collaboration Around The Table. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS '09)*, 189–196. DOI:https://doi.org/10.1145/1731903.1731939

[9] Tom Geller. 2006. Interactive Tabletop Exhibits in Museums and Galleries. *IEEE Computer Graphics and Applications* 26, 5 (2006), 6–11. DOI:https://doi.org/10.1109/MCG.2006.111

[10] Robyn M. Gillies and Adrian F. Ashman. 1996. Teaching Collaborative Skills To Primary School Children in Classroom-Based Work Groups. *Learning and Instruction* 6, 3 (1996), 187–200. DOI:https://doi.org/10.1016/0959-4752(96)00002-3

[11] Wooi-Boon Goh, Wei Shou, Jacquelyn Tan, and G.T. Jackson Lum. 2012. Interaction Design Patterns for Multi-Touch Tabletop Collaborative Games. In *Extended Abstracts of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*, 141–150. DOI:https://doi.org/10.1145/2212776.2212792

[12] Amanda Harris, Jochen Rick, Victoria Bonnett, Nicola Yuill, Rowanne Fleck, Paul Marshall, and Yvonne Rogers. 2009. Around The Table: Are Multiple-Touch Surfaces Better Than Single-Touch For Children's Collaborative

Interactions? In *Proceedings of the International Conference on Computer-Supported Collaborative Learning (CSCL '11)*, 335–344. DOI:https://doi.org/10.3115/1600053.1600104

[13] Sanna Järvelä and Allyson F. Hadwin. 2013. New Frontiers: Regulating Learning in CSCL. *Educational Psychologist* 48, 1 (2013), 25–39. DOI:https://doi.org/10.1080/00461520.2012.748006

[14] Paul Marshall, Rowanne Fleck, Amanda Harris, Jochen Rick, Eva Hornecker, Yvonne Rogers, Nicola Yuill, and Nick Sheep Dalton. 2009. Fighting for Control: Children's Embodied Interactions When Using Physical and Digital Representations. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*, 2149. DOI:https://doi.org/10.1145/1518701.1519027

[15] Paul Marshall, Eva Hornecker, Richard Morris, Nick Sheep Dalton, and Yvonne Rogers. 2008. When the Fingers do the Talking: A Study of Group Participation with Varying Constraints to a Tabletop Interface. In *IEEE International Workshop on Horizontal Interactive Human Computer Systems (TABLETOP '08)*, 33–40. DOI:https://doi.org/10.1109/TABLETOP.2008.4660181

[16] Charlie McDowell, Linda Werner, Heather E. Bullock, and Julian Fernald. 2006. Pair Programming Improves Student Retention, Confidence, and Program Quality. *Communications of the ACM* 49, 8 (2006), 90–95. DOI:https://doi.org/10.1145/1145287.1145293

[17] Christian Muller-Tomfelde and Morten Fjeld. 2012. Tabletops: Interactive Horizontal Displays for Ubiquitous Computing. *Computer* 45, 2 (2012), 78–81. DOI:https://doi.org/10.1109/MC.2012.64

[18] Izabel C. Olson, Zeina Atrash Leong, Uri Wilensky, and Mike S. Horn. 2011. "It's just a toolbar!" Using Tangibles to Help Children Manage Conflict Around a Multi-Touch Tabletop. In *Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction (TEI '11)*, 29–36. DOI:https://doi.org/10.1145/1935701.1935709

[19] Jean Piaget. 1983. Piaget's Theory. In *Handbook of Child Psychology*, P. Mussen (ed.). Wiley & Sons, New York, NY, USA. DOI:https://doi.org/10.1007/978-3-642-46323-5_2

[20] Anne Marie Piper and James D. Hollan. 2009. Tabletop Displays for Small Group Study: Affordances of Paper and Digital Materials. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*, 1227–1237. DOI:https://doi.org/10.1145/1518701.1518885

[21] Anne Marie Piper, Eileen O'Brien, Meredith Ringel Morris, and Terry Winograd. 2006. SIDES: A Cooperative Tabletop Computer Game for Social Skills Development. In *Proceedings of the ACM Conference on Computer-Supported Cooperative Work (CSCW '06)*, 10 pp. DOI:https://doi.org/10.1145/1180875.1180877

[22] David Preston. 2006. Using Collaborative Learning Research To Enhance Pair Programming Pedagogy. *ACM SIGITE Newsletter* 3, 1 (2006), 16–21. DOI:https://doi.org/10.1145/1113378.1113381

[23] Jochen Rick, Amanda Harris, Paul Marshall, Rowanne Fleck, Nicola Yuill, and Yvonne Rogers. 2009. Children Designing Together On A Multi-Touch Tabletop: An Analysis Of Spatial Orientation and User Interactions. In *Proceedings of the International Conference on Interaction Design and Children (IDC '09)*, 106–114. DOI:https://doi.org/10.1145/1551788.1551807

[24] Jochen Rick, Paul Marshall, and Nicola Yuill. 2011. Beyond One-Size-Fits-All: How Interactive Tabletops Support Collaborative Learning. In *Proceedings of the International Conference on Interaction Design and Children (IDC '11)*, 109–117. DOI:https://doi.org/10.1145/1999030.1999043

[25] Toni Kempler Rogat and Lisa Linnenbrink-Garcia. 2011. Socially Shared Regulation in Collaborative Groups: An Analysis of the Interplay Between Quality of Social Regulation and Group Processes. *Cognition and Instruction* 29, 4 (2011), 375–415. DOI:https://doi.org/10.1080/07370008.2011.607930

[26] Yvonne Rogers, Youn-kyung Lim, William R. Hazlewood, and Paul Marshall. 2009. Equal Opportunities: Do Shareable Interfaces Promote More Group Participation Than Single User Displays? *Human–Computer Interaction* 24, 1–2 (2009), 79–116. DOI:https://doi.org/10.1080/07370020902739379

[27] Karen Rust, Meethu Malu, Lisa Anthony, and Leah Findlater. 2014. Understanding Child-Defined Gestures and Children's Mental Models for Touchscreen Tabletop Interaction. In *Proceedings of the International Conference on Interaction Design and Children (IDC '14)*, 201–204. DOI:https://doi.org/10.1145/2593968.2610452

[28] Stacey D. Scott, M. Sheelagh T. Carpendale, and Kori M. Inkpen. 2004. Territoriality in Collaborative Tabletop Workspaces. In *Proceedings of the ACM Conference on Computer-Supported Cooperative Work (CSCW '04)*, 294–303. DOI:https://doi.org/10.1145/1031607.1031655

[29] Stacey D. Scott, Karen D. Grant, and Regan L. Mandryk. 2003. System Guidelines for Co-Located, Collaborative Work on a Tabletop Display. *Proceedings of the ACM Conference on Computer-Supported Cooperative Work (CSCW '03)*, 159–178. DOI:https://doi.org/10.1007/978-94-010-0068-0_9

[30] Stacey D. Scott, Regan L. Mandryk, and Kori M. Inkpen. 2002. Understanding Children's Interactions in Synchronous Shared Environments. *Proceedings of the International Conference on Computer-Supported Collaborative Learning (CSCL '02)*, 333–341. DOI:https://doi.org/10.1.1.58.9066

[31] Anthony Tang, Melanie Tory, Barry Po, Petra Neumann, and Sheelagh Carpendale. 2006. Collaborative Coupling over Tabletop Displays. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '06)*, 1181–1190. DOI:https://doi.org/10.1145/1124772.1124950

[32] Anthony J. Viera and Joanne M. Garrett. 2005. Understanding Interobserver Agreement: The Kappa Statistic. *Family Medicine* 37, 5 (2005), 360–363.

[33] Richard T. White and Richard F. Gunstone. 1992. *Probing Understanding*. Falmer Press, New York. DOI:https://doi.org/10.4324/9780203761342

[34] Laurie A. Williams and Robert R. Kessler. 2000. The Effects of "Pair-Pressure" and "Pair-Learning" on Software Engineering Education. In *Proceedings of the Conference on Software Engineering Education and Training (CSEET'00)*, 59–65. DOI:https://doi.org/10.1109/CSEE.2000.827023

[35] Nesra Yannier, Kenneth R. Koedinger, and Scott E. Hudson. 2013. Tangible Collaborative Learning with a Mixed-Reality Game: EarthShake. In *Proceedings of the International Conference on Artificial Intelligence in Education (AIED '13)*, 131–140. DOI:https://doi.org/10.1007/978-3-642-39112-5_14

[36] Open Exhibits | Multitouch, Multiuser Software for Museums. Retrieved from http://openexhibits.org/

[37] Get Microsoft Paint. *Microsoft*. Retrieved from https://support.microsoft.com/en-us/help/4027344/windows-10-get-microsoft-paint

Received April 2018; revised July 2018; accepted September 2018.