Lo-Fi Prototyping to Design Interactive-Tabletop Applications for Children

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ABSTRACT

Interactive tabletops are an exiting new platform for supporting children's collaboration. With design guidelines and standardized interaction principles still immature, there is a considerable need for iterative prototyping to define the task and interface. Lo-fi prototypes—using cardboard, paper, etc.—are easy to develop, flexible to adjust during design sessions, and intuitive for users to manipulate. Using them can be a valuable step in designing tabletop applications.

In this paper, we detail the design process of two tabletop applications, concentrating on the role of lo-fi prototyping. TransTime is a pattern game for 5–6 year olds to engage how time progresses. OurSpace is a design tool for 7–9 year olds to arrange desks and assign seats for students in their classroom. By comparing the experiences, we arrive at a better understanding of the benefits, challenges, and limits of using lo-fi prototypes to design interactive-tabletop applications for children.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces – *user-centered design*.

General Terms

Design, Human Factors.

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Keywords

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TABLETOP APPLICATIONS FOR CHILDREN

Interactive tabletops are large horizontal displays that several users can interact with simultaneously. Depending on the underlying technology, users interact through direct touch [3, 7], pen input, or by moving trackable objects [10]. As *single display groupware* [29], they lend themselves to co-located collaboration. Several projects have used these with children to promote creativity [2, 12, 13], interaction [19], and learning in a variety of subject domains: reading [28], fractions [24], and the physics of light [20]. While there is growing interest, little has been written about design methods for developing interactive-tabletop applications for children. In this paper, we examine one design method, lo-fi prototyping, and demonstrate its usefulness as part of a user-centered design (UCD) process.

We detail the role of lo-fi prototyping in the development of TransTime and OurSpace. We share our experience to concretely demonstrate the value of this approach. We then synthesize across these designs and related literature to examine the benefits, challenges, and limits of this approach. Our aim is to provide a useful guide to others interested in designing interactive-tabletop applications for children.

LO-FI PROTOTYPING

Creating software that users find useful and usable is challenging. Although seductive to novice programmers, programming software to specifications is not effective. User feedback is required to form an accurate impression of how people will appropriate a technology [18]; this requires iterative development. To ensure that development time is not wasted on implementing flawed ideas, users should be involved early in the design process [17]. Since it is often not feasible to have fully working software early in the design phase, a viable strategy is creating *prototypes*—models that partially embody a vision of the final product.

How closely a prototype resembles a working product is its *fidelity* [26]. From a user's perspective, high fidelity (hi-fi) prototypes are almost indistinguishable from a final product (at least in some aspect). Low fidelity (lo-fi) prototypes do not closely match a final product; they are created quickly with convenient materials (e.g., paper, transparencies) and lack inherent interactivity. Lo-fi prototypes are more suited to examining early ideas. Hi-fi prototypes are more suited towards finding usability problems and incremental innovation. Lo-fi prototypes have been used to develop software for a variety of platforms.

Using lo-fi prototypes became an established technique when software design was still principally concerned with creating interfaces for desktop computers. One technique is to prototype a desktop interface with paper [21]; interactivity is simulated by a human familiar with how the interface is supposed to work, leading to a controllable, albeit slow, interface. For modeling new mobile systems, creating and manipulating physical objects was demonstrated to be more useful than using high-tech devices and sophisticated software [31]. For tangible user interfaces (TUIs), where physical objects are used to interact with a digital system, a lo-fi prototype may have the same physical interface as the final system [30].

TWO CASES

We present two cases of using lo-fi prototypes to design interactive-tabletop applications for children. Each case starts by providing motivation for the project and introducing the intended users. Then, a section details the lo-fi prototype sessions and how they impacted the design. Finally, a section focuses on the transition from lo-fi prototype to software application. We provide these successful applications of lo-fi prototyping to concretely illustrate the benefits of this approach. In a later section, we synthesize across these experience to discuss the benefits, challenges, and limits of lo-fi prototyping.

TransTime

TransTime was created to help children develop their *diachronic thinking*—the capacity to understand changes that occur across time. Children aged 5–7 first have the capacity to engage these concepts [16]. In the UK, it is a specific curriculum goal for that age group. As children learn particularly well through play activities [32], we chose to create an activity that would allow children to work together on completing a task.

Early work concentrated on exploring both what aspects of diachronic thinking should be addressed and what interface (desktop PC, electronic whiteboard, or interactive tabletop) would best suit children's collaboration. Six initial ideas of time-related tasks were sketched out: 1) splitting up time into smaller pieces (year, month, day, etc.), 2) comparing different time telling devices (e.g., the sun, a calendar, a candle), 3) examining how long common activities take (e.g., eating a meal, tying your shoes), 4) matching calendar months with seasons, 5) studying the life cycle of a butterfly, and 6) matching up an analog and a digital clock. These six ideas were then prototyped as desktop PC games using Adobe Director and trialled with children of the appropriate age. Based on that session, idea 5 was selected as having the most potential. To refine that idea, the design process switched to lo-fi prototypes.

Figure 1. A poster-board prototype

Lo-fi Prototypes

The life cycle of a butterfly is one example of where an entity changes qualitatively over the course of time. To expand the task, four other such stories were conceived: 1) human life from infant to old age, 2) from seed through bud to tree, 3) activities during a typical school day, and 4) making a cake from ingredients. These are all stories that children are familiar with but also represent diversity in passage of time (i.e., different time scales and subjects). To actively engage children in joint play, the design team chose a puzzle task for engaging the stories.

When working on a puzzle, children can match up and order pieces to assist their thinking about the conceptual task [33]. Children are adept at lining objects up and making interlocking pieces fit together. They can then use those skills to help them complete a task. An early lo-fi prototype used 2D shapes on poster-board for the design team to discuss how puzzle pieces could fit together (Figure 1). Based on working with those pieces, a standard arrow shape (see Figure 2) was adopted, with the first piece missing the tail and the last piece missing the head. That shape is recognizable in terms of indicating a direction (in this task, from early to late in time). For the classroom observation, the arrow shapes were converted into three dimensional boxes to make it easier for the children to hold and manipulate objects. While many children at that age have sufficiently developed fine motor skills, there are a significant few who lag behind their peers [6].

The lo-fi prototype was then trialled with children in the

Figure 2. Children playing the game

classroom. The activity started as a competitive guessing game. The 25 boxes, five for each temporal sequence, were placed face down (Figure 2). Players took turns in choosing a piece; a player kept a piece if he chose to build that story. If the chosen piece did not belong in the story, then that piece was placed back face-down. The game continued in this manner until all objects were taken. Players were to remember where a pictured piece was placed on the table, given it was the piece they needed to build their story. The player collecting the most stories won. Children then constructed stories in a temporal sequence. In this session, a majority of the time was spent finding the pieces rather than arranging the sequences in order. Because of this, it was not clear whether the children really engaged the domain concepts. Considering the limited time allowed for such activity in the classroom, the task also took too long.

A second session was conducted with children. The task was changed from competing against each other to working together to place the face-up pieces into the five sequences. This session was more successful, with children negotiating the domain concepts better. It encouraged high levels of collaboration and gave insights into how children relate to their peers around them. There were still problems with the task. Some children placed objects in the wrong sequence or in the wrong order without realizing it. Some had difficulty building the story. Some did not connect objects in their intended position (Figure 3). The lo-fi interface provided no inherent feedback about whether pieces were placed correctly, so the children had a hard time knowing whether they were making progress. For a learning task, the system needs to provide enough feedback to allow learners to reflect on their errors.

In addition, some less expected behaviors were observed, in which the children appeared to subvert the intent of the activity. Rather than making mistakes or finding the activity difficult, they were able to interact with the objects in very deliberate and creative ways that made the activity more competitive, sometimes at the expense of collaboration. One example of this was when one child would pick up and amass a collection of objects and then begin assembling stories. This

Figure 3. Children constructing a story

Figure 4. Dropping sequences in TransTime

hoarding behavior meant that the objects were taken out of the collaborative space and made unavailable to others.

Transition to Software

As the task had proved largely successful, the software version started off following the physical task closely. Similar shaped digital pieces were created for each of the physical tiles. The pieces start off randomly scattered around the tabletop. The pictures were refined to fix some ambiguity that children had in identifying previous images and to fit in the lower resolution of the interactive tabletop. When dropped near each other, the tiles attach to form a sequence. That sequence stays together when moved, unless pulled apart by multiple fingers on the same sequence. To give feedback about correct sequence placement, musical tones are associated with each piece. When a sequence is dropped, the tones are played in sequence with the tile border highlighted when that tile's note is played (bottom of Figure 4). A different instrument was used for each sequence. Sequence order is reflected by increased pitch, with a complete sequence presenting a major seventh chord. Unlike the lo-fi prototypes, children could not rotate pieces.

This version was tried with children. The children were able to manipulate the virtual pieces and found the task engaging. However, the audio feedback proved slightly too subtle, with children still taking a long time to complete the task. To provide more obvious feedback, the software was changed so that wrongly placed tiles would highlight in red (such as the ingredients turning into a caterpillar in Figure 4) and the sequence stops playing at the wrong piece.

OurSpace

OurSpace was developed to study how children collaborate on a meaningful and challenging design task with an interactive tabletop. We started with the idea of children designing a desk layout and seating arrangement for their classroom. How are the desks grouped? Who should sit next to whom? Who should sit at the front, middle, and back of the class? This is a task a teacher normally does; here, we provide the opportunity for children themselves to explore how to accomplish it. As children have ample experience in using existing classroom arrangements, the task should be *personally meaningful*, engaging both their attention and their expertise. Our design challenge was refining the task to make it challenging enough to require collaboration and compromise.

Lo-Fi Prototypes

Research participants were recruited from a year 4 classroom (aged 8–9) in the UK. Based on a visit to the classroom and viewing architectural plans, we drew a floor-plan of the students' classroom the size of our interactive tabletop. Students worked in groups of three, seated around three sides of a rectangular table, with the drawn floor-plan in the middle. We provided cardboard cutouts of existing desks and cardboard icons to represent students. Participants were asked to work together to position the desks and students.

In the first session, the student icons were labeled with the names of children's classmates and colored blue or pink to indicate gender (Figure 5). All participants were highly engaged by the task. They were able to apply their previous experience to come up with criteria for a successful classroom plan: who was friends with whom, which children were likely to talk and be disruptive if paired with particular other students, etc. While this session largely validated the initial idea, it also exposed several problems with the task. The role of gender in seating was discussed excessively, possibly because gender had been made conspicuous by the color coding of icons. As gender is such an organizing property at that age [1], we did not want the groups to fixate on that as a criteria for seating. Children also focused on their own friendship groups and preferences at the expense of considering the class in general. Individuals were singled out for various reasons and left to sit on their own in the classroom plan; there was concern this might encourage bullying. Furthermore, the desk arrangements that the children created were largely impractical, not allowing enough walking space to traverse the classroom.

Based on what we learned, we redesigned the task. The scenario was changed to participants creating a seating arrangement for the class coming in next year. The class was fictitious, but we kept to the same number of students and desks as the current class. To avoid gender biasing, we labeled the students with gender-neutral names. Even though the names were largely meaningless, the labels were useful for both participants and researchers to refer to specific students. To make the task more challenging and engaging, we added different characteristics to the student icons based on criteria that students mentioned during the previous iteration (Figure 6). Friendship groups were indicated by icon color; to simplify, there were no overlapping friendship groups. Talkative students had an open mouth and speech bubble. Those with vision problems were shown with glasses. We felt that the children in the first session had a problem envisioning the two dimensional floor-plan as a three dimensional space. To encourage thinking of it as a three dimensional space, tabs were added to the icons (Figure 7). When the tabs were placed properly under a desk, the student icon would stick up similar in position to a seated student.

Figure 5. A design in the first session

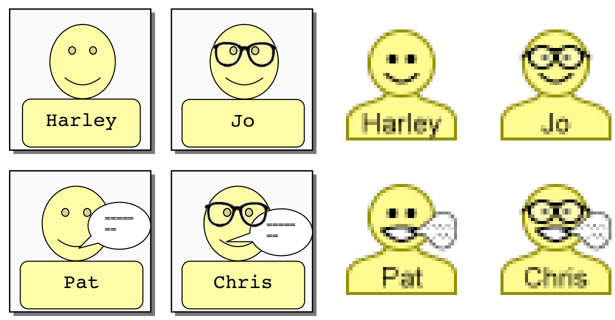

Figure 6. Student icons for the cardboard pieces (left) and software (right)

In a second session with new participants from the same class, we tested the new design. The tabs proved immediately problematic. They were difficult for the children

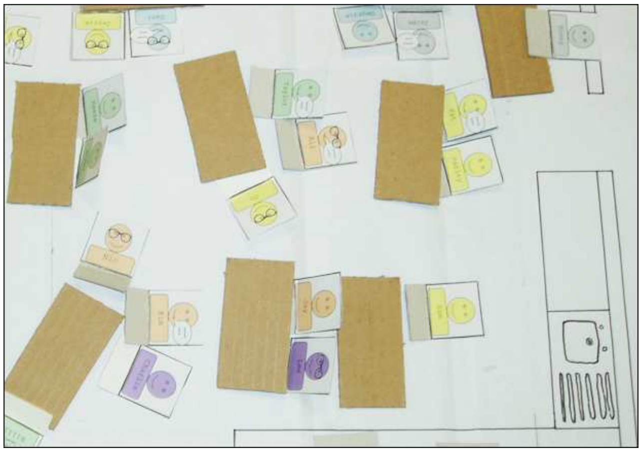

Figure 7. Student icons with tabs

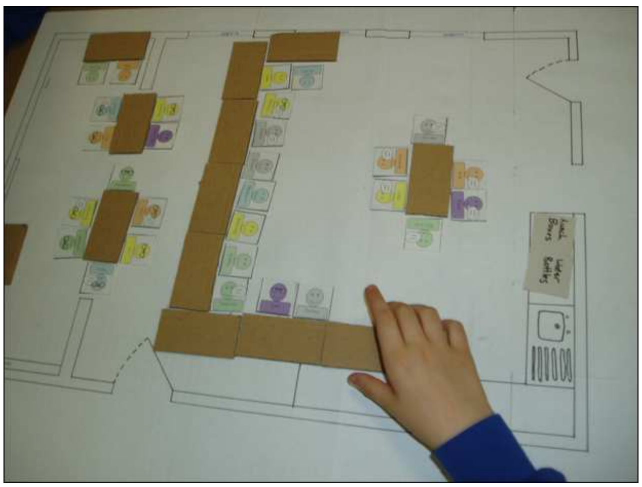

Figure 8. A design in the second session

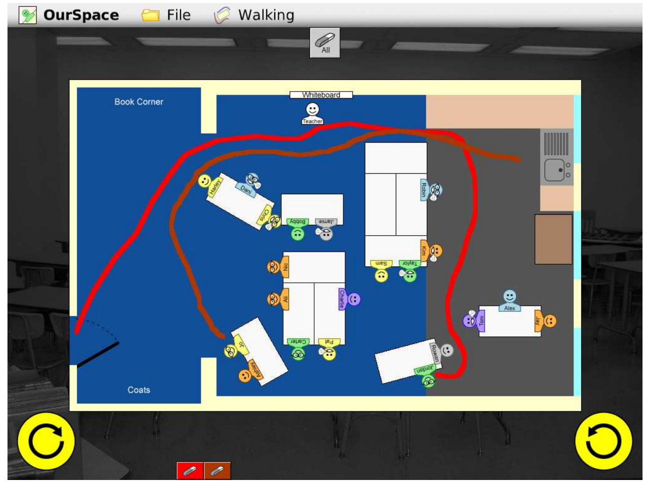

Figure 9. A design created with OurSpace

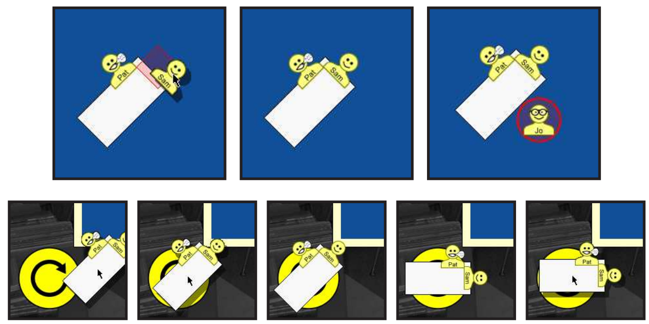

Figure 10. Placing students (top) and rotating a desk (bottom)

to place properly and fell down frequently. After the first group, we cut off the tabs. The other changes proved viable. Children bought into the scenario and were still highly engaged with the task. They also were able to use the icon characteristics for reasoning about design decisions. Participants still created designs that were impractical; Figure 8 shows one design where people would have to cross over a barrier of desks to cross the room. We were sufficiently happy with this lo-fi prototype to move forward with a software version.

Transition to Software

The OurSpace software was designed to closely match the lo-fi prototype and to compensate for its weaknesses. The floor-plan was colored to accentuate the difference between wall and floor (Figure 9). Participants use their fingers to drag icons of students and desks onto the classroom plan. The student icons were redesigned to work in the lower resolution of the projected image on the tabletop (Figure 6). One of the larger usability problems with the lo-fi prototypes was that it was difficult for children to move a desk without losing the associated student icons. Children could either place the students on the desks (Figure 5) to facilitate desk movement or position them around the desks (Figure 8) to facilitate thinking of the space needed by seated students. To facilitate both movement and spatial conception, the software version allows student icons to be snapped to the desk. When a student is dragged over an available desk seat, the seat is highlighted and the student icon is oriented toward that seat position (Figure 10: Top Frame 1); when dropped, the student icon snaps to that seat (Figure 10: Top Frame 2). Once a student is in a desk seat, he or she moves along with the desk; students can also be dragged out of their seat to relocate them. To rotate desks, users drop them on rotation areas at the bottom left and right of the screen (bottom of Figure 10). When on a rotation area, a desk rotates 15 degrees[1] every 600 ms, pausing for an extra cycle in vertical and horizontal positions since these are most likely the wanted orientations. When desks are dropped near each other, they snap to each other so that there is no visible gap between the desks.

A session using the OurSpace software was run to improve its usability. This helped to refine the software in several ways. The timing of the rotation area was adjusted until it was found to be slow enough for participants to use, but

[1] 15 degrees is a convenient increment of rotation as it allows desks to be easily rotated to 45 degrees (i.e., along a diagonal) and 60 degrees (useful for creating equilateral triangles and hexagons).

fast enough not to seem tedious. In the initial version of the software, the seating snaps were confined to the desk itself (i.e., much smaller than those shown in Figure 10: Frame 1). Consequently, participants did not intuitively understand that they were supposed to snap the students to the desks. Once told of this feature, they were able to use the smaller snaps, but larger snaps made this easier and more intuitive. To further emphasize the need to seat students, students dropped in the room but not seated show a red halo around them (Figure 10: Frame 3). To facilitate thinking about the movement of students in the room, we added a walking mode in which participants could draw on the floorplan to simulate routes that students might take (Figure 9); thus, students could more easily reflect if their plans made movement impractical (something that did still occur).

REFLECTIONS ON THIS APPROACH

These cases demonstrate that lo-fi prototyping can be useful for designing applications with different audiences, tasks, and goals. TransTime is for 5–6 year olds; OurSpace is for 7–9 year olds. TransTime is a puzzle game; OurSpace is a design tool. TransTime was created to promote learning; OurSpace was created to study collaborative design. Until the jump to software, the designs were done by separate design teams.[2] Given these substantial differences, there are remarkably similar benefits and challenges to lo-fi prototyping. As such, we believe these benefits and challenges apply broadly to using lo-fi prototyping to design interactive-tabletop applications for children. In this section, we reflect on the benefits, challenges, and limits of this approach.

Benefits

Lo-fi prototyping is an established technique for user-centered design. It is a versatile technique, applicable to a variety of technologies, ranging from desktop interfaces [21] to creating novel mobile devices [31] and TUIs [30]. This wide scope is due to some of its benefits being universal (i.e., applicable across technologies). Here we separate the universal benefits (i.e., those that would apply to desktop technologies as much as to interactive tabletops) from those particularly applicable to interactive tabletops.

Applicable to All

First, *lo-fi prototypes are easy to develop*, requiring no programming skills. Designing for children is particularly challenging as they tend to view the world differently than adults [4]. For developers not intimately familiar with children of that age, it is often difficult to judge whether an activity is too advanced or alternatively patronizing [25]. Since it requires no programming experience, the development of the lo-fi prototypes can be done by someone who better understands children of that age. For both TransTime and OurSpace, most of the design work was carried out by designers who had knowledge of how children of that age collaborate but without programming acumen. Then, a programmer was able to take these visions and develop useful tabletop applications with a relatively small amount of revision.

[2]The digital interfaces were programmed by the same developer, but that developer was not involved in the lo-fi prototype process.

Second, *lo-fi prototypes are flexible*, allowing designers to adjust them easily. A design can be adjusted between sessions or even during a session if need be. A designer can also guide the interaction, providing help when things do not work as expected or simulating part of the system (e.g., informing users that their solution to a puzzle is correct). When using TransTime as a competitive game proved to be ill conceived, no extra development had to be carried out in order to radically change the task for the second session. When the tabs proved to be frustrating to the OurSpace users, they were cut off before another user group arrived.

Third, *lo-fi prototypes are intuitive for users to manipulate*. Users already have substantial experience in manipulating physical objects that they can apply to the task [35]. As tabletop interfaces are still relatively novel, there will be inherent usability problems with children first getting used to the interface and its conventions. For instance, young children often find it difficult to use common tabletop maneuvers such as drag-and-drop because they lack some of the necessary fine motor skills [12]. Lo-fi prototyping sidesteps those issues and allows the early design process to concentrate on establishing the task, rather than worry about interface usability problems which are best addressed later in the design process. With the exception of the tabs, children had no problem using the physical pieces to complete the tasks. The children were not informed that they were completing these tasks so that we could design software. To them, the prototype task was the real task and they did fairly well with it.

Specific to Tabletops

First, *lo-fi prototypes afford concurrent collaboration*. Unlike other digital interfaces (desktops, handhelds, and most electronic whiteboards), interactive tabletops allow concurrent input. They are at their most compelling when supporting concurrent collaboration [24]. So, an interactive tabletop can offer a similar style of collaboration as the lo-fi prototype. In contrast, using lo-fi prototypes to design a system that requires turn taking (e.g., most electronic whiteboards) would require imposing turn-taking on the task; however, children want to be continuously engaged in a task. During the early TransTime sessions, when it was envisioned as a turn-taking game, the children found it difficult to wait for their turn and became easily distracted. When fewer constraints were imposed, children chose to act simultaneously for both applications. In contrast, adults working on a similar planning task as OurSpace where observed to frequently take turns and to verbally discuss actions before implementing them [15]. So, this advantage (interactive tabletops matching concurrent collaboration) is particularly important when designing for children.

Second, *collaborative tasks lend themselves to observation*. The purpose of iterating with lo-fi prototypes is to gain insight into how users engage the task. This is often challenging when working with children. A single child working with a desktop prototype has little reason to communicate his thinking. For adults, think aloud protocols, where an single user voices her thoughts and narrates her actions, have been found to be useful in gaining such insight. Yet, it is difficult to have (young) children follow such an artificial method. Fortunately, the tasks that are compelling for interactive tabletops are collaborative. Children working together are frequently compelled to communicate with each other through speech or gestures. As a designer, these communications can provide insights into their thinking. Thus, designers can get a sense of whether and how children collaborate on a task. For OurSpace, we were able to integrate the criteria that children articulated for placing their own class into the task.

Third, *there is a useful mapping between the lo-fi prototype and interactive tabletop interfaces*. Moving physical objects requires taking a hold of an object, moving your hand, and then releasing your hold of the object. While it might be implemented slightly differently, the same process applies to moving virtual objects on an interactive tabletop. Because it requires large physical movements in a shared space, other collaborators can be aware of the actions. This awareness is critical to collaborating using interactive tabletops [5, 20]. The transition from pointing to an object in order to communicate with a collaborator and then taking some action with that object is similarly quick. Even though there were significant differences in how objects moved on the tabletop (e.g., no rotation in TransTime, a decoupling of rotation and translation in OurSpace), children had little problem using the digital interfaces. Because the mapping to physical objects was good, the tabletop interfaces were intuitive to use and the collaborative nature of the task was maintained.

Challenges in Switching Interfaces

While the mapping is good, lo-fi prototypes and interactive tabletops afford different actions and possibilities. Small improvements in the lo-fi prototype are likely to be wiped out by this interface switch. Thus, iterations on the lo-fi prototype are only useful if they further inform designers about how children collaborate or substantially help to refine the task. For both TransTime and OurSpace, the time was right after two user-tested iterations. At that point, the major design challenges were no longer ones easily addressed by improvements in the lo-fi prototype. For TransTime, the children needed feedback on their task progress. For OurSpace, the children needed ways to attach student icons to desks and to better reflect on the practicality of their designs. These design challenges were better addressed through software. In terms of improving the design, the switch from lo-fi prototype to a digital interface has both advantages and disadvantages.

Advantages

Physical objects have set affordances. Children can pick them up, hold them, or even hide them. These behaviors have an impact on the children's ability to engage in collaborative exploration [14]. Interactive tabletops cannot replicate all of these actions. In early stages of the design, this flexibility allows users to appropriate the objects in novel ways, often inspiring designers to rethink the interface or task. As the task and interface settle, it becomes difficult to constrain the uses of the physical objects to just those envisioned by the designers. This is a substantial problem for designing TUIs as users will infer that tasks done with the physical object will affect the digital system, even if the technology cannot infer it [9].

A major advantage of digital interfaces is that they can structure and constrain the task to provide feedback to users [22]. For TransTime, the puzzle pieces were constrained to stay in one orientation (i.e., no rotation). They were structured so that pieces could be attached to each other to form a sequence which would stay together until pulled apart. To provide subtle feedback on task progress, musical tones were associated with each piece. To provide more obvious feedback, a puzzle piece in the wrong position would glow red when the sequence was played. For OurSpace, desks were structured so that student icons could be snapped to them, facilitating easier movement of full desks. Red halos around student icons not positioned on a desk provided feedback about the need to associate student icons with desks. In "walking" mode, the position of the student icons and desks was frozen to focus the children on how the current design supported movement around the classroom. For both applications, children were observed to hoard pieces to control them, often removing them from the shared space. The tabletop interface constrained the pieces to the shared space, lessening the ability of children to hoard resources.

Digital interfaces also enable saving designs, undoing actions, and altering objects. TransTime tiles could be made to glow in sequence when dropped. OurSpace designs could be saved and reopened. Trails could be drawn on the floor-plan to indicate movement and then be removed.

Disadvantages

One disadvantage to interactive tabletops is that applying physical movements to virtual objects is not straightforward. Virtual objects cannot be lifted above the tabletop surface. They also do not provide tactile feedback. In TransTime, the lo-fi prototypes were easy to push together. In OurSpace, the lo-fi desks could be aligned by pushing them together. While it would be possible to create a virtual interface that allows objects to collide, it would be hard to decide whether the intended action is to lift the object over the other objects or to have them collide. Instead, for both TransTime and OurSpace, snapping was implemented. If a piece was dropped sufficiently close to a piece it could attach to, the dropped piece would snap to the aligned position. As TransTime pieces were larger and the intended users were younger, the distance to snap them together was chosen to be roughly double that of OurSpace desks. Snapping proved to be a good solution for getting the position correct.

In OurSpace, there is the additional requirement that the rotation angle needs to match for the desks to line up. To solve this, we limited rotation of desks to 15 degree increments and used rotation areas to accomplish the rotation. There are more sophisticated ways of handling rotation on touch surfaces. Rotation and translation can be combined into one gesture if the object is touched on the outside [11]. This technique did not seem promising for OurSpace as the tables were already fairly small and the outsides were mainly used for positioning student icons. Another possibility is using a secondary touch point to handle rotation while the primary touch point handles translation [8]. Such a method was implemented in RoomPlanner [34], a more sophisticated room-layout application for interactive tabletops. RoomPlanner was designed to showcase innovative touch interfaces (e.g., using a vertical hand side to sweep multiple pieces along) and was used with adults; OurSpace was designed to be easy for children to learn and us. For our purposes, the rotation areas worked well.

One unanticipated challenge in adapting TransTime and OurSpace lo-fi prototypes to software is that there is a significant difference in resolution between paper and electronic displays. Printed paper can have an extremely high resolution, not showing any pixelation to a human eye. In contrast, our tabletop setup (a small DiamondTouch table with an XGA projector) has a low resolution of 41dpi. The pixelation is readily apparent (see Figure 6). If virtual keystoning is used, the clarity of a projector image can fall further. For TransTime, this meant that images had to be altered or replaced so that they would still be identifiable. For instance, the picture of the butterfly eggs had to be zoomed in upon so as not to appear as a white smudge. For OurSpace, the pixel size of the classroom, and thereby the size of the desks and students, was constrained by what would fit on the table. This meant that a small font (9-point) needed to be used. Special care had to be exercised so that these labels could still be read when the student icon was rotated at odd angles.

Limits

While we recommend this method, we do acknowledge its limits. First, it has limited applicability. We confine our process to designing tasks where children collaborate using an interactive tabletop. Without the collaboration, the observation style of monitoring participants' thinking would have to be altered. Second, since the software matches the physical prototype, the virtual objects behave similar to physical objects. In both TransTime and OurSpace, the virtual objects are persistent and are just to be moved around. While such consistency with the physical world is useful in allowing new users to grasp the interface, it does not take full advantage of the expressiveness of multi-touch tabletops. It is hard to see how something as common to touch-based applications as pinching to zoom out can be integrated into the lo-fi prototype stage. Third, we follow a relatively traditional UCD relationship with the developers presenting prototypes to users and seeing how they work with them. In the last decade, the role that children can play in the design process has been expanded. Researchers have shown the value of treating children as informants [27] or even design partners [4].

While lo-fi prototyping is a useful approach, there are other ways to successfully design interactive-tabletop applications for children. For instance, adapting an existing desktop application to a tabletop can bypass much of the early phases of design work [23].

CONCLUSION

In this paper, we shared our success in using lo-fi prototypes to design two interactive-tabletop applications for children. Both design teams followed a user-centered design approach through three iterations (two iterations with lo-fi prototypes, one iteration with software) to design useful and usable tabletop applications within a reasonable time frame. The majority of the design work was carried out by designers with expertise in working with children, but without programming skills. We synthesized across our experiences to arrive at a better understanding of the benefits of lo-fi prototyping and the challenges involved in switching from a lo-fi prototype to an interactive tabletop. We hope that our experiences can guide others interested in developing applications for interactive tabletops.

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