Mad Mixologist: Exploring How Object Placement in Tangible Play Spaces Affects Collaborative Interaction Strategies

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***Abstract*—Tangible games afford an engaging and often unique form of hybrid play (i.e., physical-digital elements), but there is currently limited work explicitly exploring how these games can be designed to provide spatial affordances that implicitly encourage collaboration. In this paper, we present a novel collaborative tangible game, titled *Mad Mixologist*, and investigate how making a simple change in the location of game objects within the tangible play space can lead to significantly different collaborative interaction strategies. The results from our group comparison study indicate that 1) players with exclusively direct access to multiple relevant resources (i.e., a digital instruction and a physical object) were more likely to assume responsibility for completing tasks in a shared play space and 2) distributing these same task-relevant resources across multiple players created ambiguity over whether the player with the digital or physical resource should engage with the shared play space. This study demonstrates one possible way in which the physical design of a tangible game can be arranged to implicitly encourage players to develop more collaborative interaction strategies, specifically by distributing exclusive resources across players. Overall, this study highlights and reinforces the connection between spatial affordances and social interactions via embodied facilitation within the context of collaborative tangible games.**

***Index Terms*—tangible games; collaborative play; interaction strategy; embodied facilitation; spatial design; augmented reality**

I. Introduction

Collaborative play is a desirable behavior in games that require individuals to work together to achieve a common goal [2], [35]. When designing a tangible game where players interact with objects in a physical environment, it is important to consider how the spatial configuration of those objects within the play space can *implicitly* encourage players to adopt a collaborative play style (as opposed to an independent or competitive style). Eva Hornecker first established a framework to guide the design of tangible interaction for collaborative use [13]. One of the four design themes—embodied facilitation—is a critical concept highlighting that *"tangible interfaces/interaction systems embody facilitation methods and means by providing structure and rules, both physically and procedurally. Any application can be understood as offering structure that implicitly directs user behavior by facilitating some actions, and prohibiting or hindering others. It thus influences behavior patterns and emerging social configurations."* [13] Due to this inherent link between physical and social affordances [14], it is especially important to consider how just the spatial design of a tangible system can influence a person's interaction strategies both with objects and other people. As a result, designers of physically collaborative games need to be aware of how embodied facilitation can be used to encourage players to engage in the intended collaborative behavior. While existing frameworks are useful for guiding game design [7], [14], it is rare to find empirical work explicitly demonstrating how embodied facilitation can impact collaborative strategies in tangible games [18]. This work aims to address this knowledge gap.

In this paper, we present an empirical study that uses a novel two-player tangible game—titled *Mad Mixologist*—to examine how object placement in a tangible play space can influence players' natural tendency to collaborate. Tangible play spaces can often be delineated into shared and personal proxemic zones, where objects in the environment are either physically accessible to a group of players or to a single individual at a time, respectively. In this case, players' physical contributions to group tasks conducted in the shared space are necessarily limited by their physical access to task-relevant resources. The *Mad Mixologist* game is designed in a way that delineates the play space into both shared (physical) and personal spaces (one digital and one physical). For this paper, we hypothesized that affording one player exclusive access to both personal spaces at a time (i.e., a digital instruction AND target object) would encourage them to develop **1) less collaborative** and **2) more consistent** interaction strategies than if each of the players was always given access to one of the exclusive resources at a time (i.e., a digital instruction OR target object). To test these hypotheses, we designed two test conditions that either 1) provided one player at a time with exclusive access to both personal spaces or 2) gave both players alternating access to one of the personal spaces at a time throughout the game. We then used video coding and timestamp analysis techniques to quantify how much time each player spent trying to interact with the physical game objects in order to statistically compare the groups' physical interaction strategies. We conclude by discussing these group comparison results and their implications for the design of collaborative tangible games [15]. Evaluating the impact of spatial affordances within the context of collaborative play should help game developers and researchers understand the potential of seemingly simple physical design choices to generate drastically different interaction strategies.

II. Related Work

A. Tangible Games

Tangibles have a longstanding history in digital games—such as the light gun that accompanied the Magnavox Odyssey, the first commercial home video game console [4], [8]. These tangible games are playful experiences created using a hybrid of physical and digital interactive elements, and are becoming more prevalent and sophisticated with modern emerging technologies such as AR, VR, and wearables [16], [17]. Notably, the hybrid interfaces of tangible games can be designed in a variety of unique ways depending on how the application intersects with current technological capabilities (e.g., tabletop interfaces or AR), which can lead to a diverse range of tangible games [33]—such as hybrid board and card games [10], [19], tangible tabletop games [24], [25], alternative controller games [12], [30], hybrid AR/tangible games [1], [22], [23], and hybrid VR tangible games [3].

B. Embodied Facilitation Guides Actions and Interactions

Hornecker's design framework identifies four interrelated themes: tangible manipulation, spatial interaction, embodied facilitation and expressive representation. The present paper focuses particularly on exploring the understudied connection between spatial interaction and embodied facilitation. The spatial interaction theme states that, because movement and perception are tightly coupled, a person perceives their functional role based on the spatial properties of the environment (e.g., "why do I act?"). Embodied facilitation focuses instead on describing *how* the properties of a tangible space can be configured to guide—and even restrict—both individual interaction strategies and emerging group behaviors (e.g., "how do I act?") [6], [14]. Critically, Hornecker highlighted that "*the support of social interaction and collaboration might be the most important ... feature of tangible interaction, but this issue has attracted little explicit attention*." While this observation was published over 15 years ago, it is still rare to find tangible game studies that explicitly demonstrate how embodied facilitation can impact collaborative interaction strategies in a tangible play space [18]. This is especially true with respect to the configuration of physical resources in the tangible play space.

C. Facilitating Collaboration in Tangible Games

When a tangible space allows users to interact with the environment and each other in flexible ways, it affords users opportunities to perform the same activity using vastly different interpersonal strategies (e.g., collaborative versus competitive play styles) [20], [23], [31]. Conversely, a tangible space can employ embodied facilitation (i.e., by guiding or restricting user actions) to encourage a more specific interactive experience [14], [21], [34]. A prime example of embodied facilitation is when objects are spread far apart across a tangible environment, forcibly limiting players' physical interactions to nearby sub-spaces [32]. Sub-spaces (whether social or physical) are an important characteristic of tangible environments to consider because they create perceived boundaries between people and/or objects [26], [27]. These imaginary boundaries can then influence players' perceived connections between various elements of the interactive environment, indicating the potential for sub-spaces to affect a user's interaction strategy.

To date, various aspects of tangible games have been evaluated in order to inform game design that drives specific interpersonal behaviors like collaboration. Some of these studies have examined the influence upon collaboration of things like replacing a traditional keyboard/mouse interface with tangible objects [23], adding tangible tools to a tabletop interface [29], enabling an environment to be configurable [9], and changing the shape of the surrounding space [5]. The current study aims to add to this list of documented game design aspects by evaluating how the configuration of objects within a tangible play space, and consequently the distribution of exclusively accessible resources between players, can significantly influence collaborative interaction strategies.

D. Definition of Collaboration

In evaluating *Futura*, an interactive tabletop game for collaborative learning, Antle et. al. [2] defined collaborative play as "*a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem*." While providing design considerations for collaborative board games, Zagal et. al. [35] added that "*collaborative players have only one goal and share the rewards or penalties of their decisions.*"

III. Design of *Mad Mixologist*

Mad Mixologist is a tangible collaborative game that utilizes augmented reality (AR) to swap the vision of its two players. Upon donning the headsets, the players learn that the main objective is to use the objects/ingredients arranged on the table between them to mix a drink. Swapping the players' perspectives decouples their visual and proprioceptive feedback (i.e., hand-eye coordination), which makes execution of these "simple" tasks much more challenging, especially if both players want to perform actions at the same time. Figure 1 shows an example of how the game is set up and what the players' perspectives look like. Assuming the players want to avoid making a mess (an implicit goal of the game), the swapped perspective design necessitates at least some collaborative effort because each player can only see from the other's field of view. This means that the player pair must communicate with each other in order to give feedback about the utility of the visual information provided

Fig. 1. Players (B) receive the others' viewpoint as well as instructions through an augmented reality headset. The video that P1 (red headset) sees is shown in A, and P2's (purple) view is shown in C. The featured game is sampled from the Unmatched group, where the bell colors do not match the nearest headsets.

by the other player. Ultimately, the players are not required to synchronize physical interactions, but this communication requirement ensures that the game enforces collaboration.

In addition to swapping perspectives, the headsets are used to present the players with a series of instructions (see Figure 1 for an example of how instruction presentation looks from the two players' points of view). For this study, the game's design was comprised of six instructions that gradually increase in difficulty and culminate in the creation of a non-alcoholic "Blushing Arnold Palmer" drink. Instructions are presented in an alternating fashion to one player at a time (see Figure 2). Player 1 (P1), wearing the red headset, receives the odd numbered instructions (i.e., 1, 3, 5), while Player 2 (P2), wearing the purple headset, sees the rest (i.e., 2, 4, 6). The player not currently receiving an instruction is instead provided with a statement intended to encourage collaboration, i.e., "Help the other player! ASK THEM HOW!"

MAD MIXOLOGIST INSTRUCTIONS

STEP	PLAYER 1	PLAYER 2
1	Ring the RED bell to start	Help the other player! ASK THEM HOW!
2	Help the other player! ASK THEM HOW!	Ring the PURPLE bell to start
3	Add SILVER cylinder to GREEN pitcher, then ring RED bell	Help the other player! ASK THEM HOW!
4	Help the other player! ASK THEM HOW!	Add PURPLE cylinder to GREEN pitcher, then ring PURPLE bell
5	Stir GREEN pitcher with YELLOW straw, then ring RED bell	Help the other player! ASK THEM HOW!
6	Help the other player! ASK THEM HOW!	Pour GREEN pitcher into both PURPLE cups, then ring PURPLE bell

Fig. 2. The six instructions provided to each player during the game. The font style of the instructions emphasizes the importance of color words—in this case, the word "red" uniquely uses red, capitalized font, while the rest of the font is a neutral blue. Each of the objects on the table are able to be identified via corresponding distinct shape-color combinations such as GREEN pitcher, SILVER cylinder, and so forth (see Figure 3).

The game starts when the red headset presents the first instruction to P1: "Ring the RED bell to start." The tasks listed in the instructions can be divided into two distinct categories: bell ringing and drink mixing. The first two instructions only involve bell ringing and are considered "practice levels" for those that come after, providing players with a single simple task to help orient themselves to this new visual perspective and form of collaboration. Each of the four remaining instructions involve ringing a bell as well, but only after completing a more challenging drink mixing task. All of the drink mixing objects are located in a shared interactive space (i.e., within reach of both players). In contrast, one bell is placed within each players' personal space (i.e., out of their partner's reach).

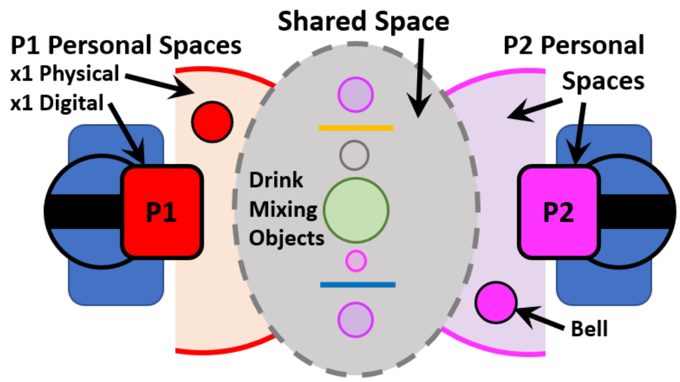

Fig. 3. Space definitions and object locations. One of two bells is located within each player's personal physical space. The drink mixing objects are located within the shared physical space (top to bottom: purple cup, yellow straw, silver cylinder, green pitcher, purple cylinder, blue straw, purple cup).

Aside from the player-specific constraints imposed by the headsets and the location of objects in the play space, both players are essentially afforded complete freedom to accomplish the instructions however possible. In other words, the game does not provide any explicit restrictions to indicate which player(s) should complete each task/instruction. This observation is important because the design of tangible interactive spaces can naturally facilitate (or restrict) users' interaction strategies within that environment. When a game does not assign players specific roles, they must instead infer appropriate interaction strategies based on the physical and social affordances imposed by the design of that interactive space. Prior research has shown that working within a completely shared interactive space is effective for encouraging cooperative experiences [23]. However, in addition to a shared space, this game's design also affords each player both physical and digital forms of personal spaces (see Figure 3) that function as exclusive access points to information (instructions) and objects (bells). Compared to an interactive space that is completely accessible to both players, the inclusion of personal spaces has the potential to alter or even disrupt cooperative interaction strategies [28].

Importantly, each player's physical personal space contains only one of the bells, which implicitly encourages both players to adopt distinct functional roles with respect to those objects.

Each player also has a digital personal space provided by the headsets, where only one player at a time has visual access to the current instruction (although players may convey the instruction to their partner).

IV. Methods

For this study, we created two versions of the *Mad Mixologist* game that were identical except for the contents of each player's physical personal space. More specifically, we switched the locations of the two bells between the two test conditions—e.g., the Matched condition placed the red bell next to the red player (P1), while the Unmatched condition placed the red bell next to the purple player (P2). In doing so, we aimed to evaluate how a simple change in the spatial configuration of objects in a collaborative tangible game would influence players' interaction strategies. We hypothesized that switching the positions of the two bells between the personal spaces would cause the players to adopt significantly different interaction strategies with respect to the objects in the shared space.

A. Procedure

This study was approved by the Institutional Review Board of the University of California, Santa Cruz. All testing was conducted in-person during a series of video game playtesting events hosted in a large event space on the university campus. Two play conditions were tested and video recorded (one condition per night): 1) the red bell was placed closer to P1 while the purple bell was placed closer to P2, and 2) the bell positions were switched (see Figure 5). All other gameplay conditions were the same between the two groups. For each game, a member of the research team closely monitored the play session. When the players successfully completed a task and rang the correct bell, the researcher operated the game's control software to manually advance the game to the next instruction. The game software documented these manual commands by saving a timestamp file.

B. Participant Recruitment

Each participant was recruited during one of two game playtesting events. All participants volunteered (i.e., they were invited but not requested) to attend the event. Once at the event, self-selected pairs of participants were recruited to play the game by the research team. Before playing, participants signed forms indicating that they agreed to participate in the study and to be audio and video recorded during all gameplay. They also completed a short demographics survey.

C. Definition of Interaction Strategy

While the *Mad Mixologist* game facilitates various forms of interaction strategies, including both social (user-user) and functional (user-object) behaviors, this paper focuses exclusively on understanding how the design of the tangible environment affects players' functional interactions with the physical game objects. More specifically, this study aims to examine the consequences of a small change in the spatial configuration of the tangible environment upon the amount of time each player spends physically completing tasks. Therefore, for the purpose of this study, the definition of an "interaction" or "interaction strategy" will be restricted to behavioral data involving players physically interacting with any of the game objects (unless stated otherwise). The following section explains how this specific type of interactive behavior was identified and quantified for analysis.

D. Behavioral Data Coding

After the conclusion of the study, the recorded videos were manually coded for behavioral data by one of the authors using the BORIS event-logging software [11]. Every participant received a unique identifier (e.g., G1-P1) during the coding process. Actions were defined as "any movement of the upper limbs" and were sub-categorized to be either interactive (i.e., functional) or gestural (i.e., emotive), and only interactive actions were statistically analyzed. Interactive actions occurred when a player clearly attempted to interact with any of the game objects placed on the table. More specifically, a START code indicated that a player started moving with apparent intent to interact with an object, and a STOP code indicated the functional conclusion of that movement (i.e., the player returned the limb close to its original neutral position). Due to feelings of disorientation, players frequently initiated interaction with objects but ceased movement during the action for extended periods of time (e.g., hovering over a bell or holding a container). These periods of time were included as part of the interaction whenever they clearly contributed to task completion. "Incorrect" actions (e.g., ringing the wrong bell) were also included as valid interactions.

E. Statistics

For each game, the total time spent completing each instruction was calculated using the timestamp data generated by the game's software. Each player's total interaction time for each instruction was calculated using the timestamp data generated by the BORIS program. Proportion of play time for each instruction was calculated by dividing a participant's total interaction time by the duration of time spent completing the instruction. Because this paper focuses mainly on comparing collaborative strategies between two test conditions, we generated a "percent total effort" metric to indicate whether one player spent more interaction time attempting to complete an instruction compared to the other player. Each player's percent total effort for each instruction was calculated by dividing their total interaction time by the sum of both players' total interaction time for that instruction. For this metric, a score of 0 or 100% for either player indicated that only one of the players contributed to the total interaction time for an instruction. Conversely, a score of 50% indicated that both players contributed equal amounts of interaction time for an instruction. This metric generated complementary data between the two players (e.g., 75% effort for P1 implies 25% for P2). Therefore, in order to simplify the presentation of group comparison results, the statistics for percent total effort data is only reported for P1. Finally, we created a metric to assess the total proportion of time that each player spent interacting with objects during the three instructions involving the same bell. This "total percent interaction time" metric was calculated by summing the total interaction time a player spent on the three instructions involving the same bell divided by the total duration of those instructions.

All data was evaluated using Matlab and is presented in the text as mean ± standard deviation (SD). For each instruction within each of the test conditions, non-parametric two-sided Wilcoxon sign rank tests with a 95% confidence interval were used to determine whether P1 on average contributed significantly more or less than half (i.e., 50%) of the total effort. Comparisons across test groups were conducted using non-parametric two-sided Wilcoxon rank sum tests with a 95% confidence interval.

V. Results

A. Participants

A total of 32 participants were recruited for this study (21 male, 9 female, 2 non-binary). Eighteen participants (9 pairs) played the game on the first round of testing (i.e., "Matched" bell-headset color condition), and fourteen (7 pairs) played on the second (i.e., "Unmatched" condition). The two groups were comparable in age (Unpaired t-test: Matched = 25.9±3.2, Unmatched = 28.1±7.0, p = 0.25) and prior experience playing AR/VR games (Wilcoxon rank sum test: p = 0.46).

B. Group Comparison of Level Completion Times

We compared the average length of time that each test group spent completing the whole game and each of the six instructions (see Figure 4). With one exception, the Matched and Unmatched groups spent statistically comparable amounts of time completing the individual instructions (first instruction: p = 0.03; other instructions: $p > 0.07$). However, the Unmatched group on average always took longer to complete each instruction. Consequently, we found that the Unmatched group spent significantly more time playing the entire game than the Matched group (Wilcoxon rank sum test: p = 0.03). In order to control for these differences in play duration, the rest of this study's results compare the amount of interaction time that P1 spent with respect to P2 within each game—creating a proportion of total effort for each pair with respect to each instruction. As such, the proportion of total effort metric describes the players' interaction strategies in a way that is independent of the total play time.

C. Matched Group Interaction Strategies

All data and statistical tests comparing the Matched players' average percent total effort to 50% are reported in Table I (see Matched columns). In the Matched game condition, P1 received three instructions involving the red bell, which was located in that same player's personal space. A series of Wilcoxon sign rank tests revealed that, for two of these instructions, P1 on average provided significantly more than

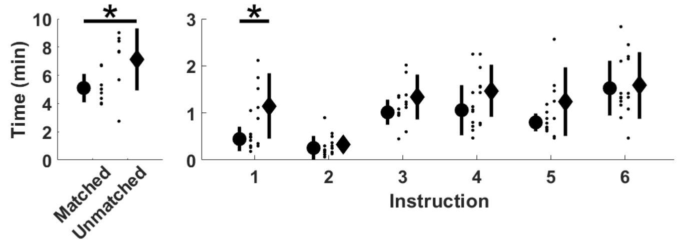

Fig. 4. Duration (in minutes) player pairs took to complete the whole game (left) and each instruction. Error bars represent group standard deviation. Small dots represent individual games. * indicates $p < 0.05$.

half (50%) of the total effort that both players spent completing the tasks. While the third red bell instruction was not significant, P1 still spent on average more than three times the amount of effort as P2. These results indicated that when P1 was afforded access to both the red bell and its corresponding instructions, that player was significantly more likely to spend effort towards completing the tasks in those instructions.

We then conducted the same analysis for the Matched P2, who received the other three instructions that instead involved the nearby target purple bell. A series of Wilcoxon sign rank tests showed that P2 consistently spent significantly more than half the total effort needed to complete each of these instructions. This pattern, combined with that from P1's red bell results, strongly suggested that both players on average chose to adopt similar complementary interaction strategies throughout the game (i.e., the players "took turns" to independently complete "their" instructions). Altogether, these results provided convincing evidence that the players with simultaneous access to both the physical and digital personal spaces were consistently significantly more likely to interact with the any of the task-relevant objects. Even though most of the interactions occurred in a shared space, both players on average reliably opted to take responsibility for their "own" tasks.

D. Unmatched Group Interaction Strategies

Statistical data for the Unmatched participants is also provided in Table I. In this test condition, P1 always received instructions about the red bell, but this target bell was inaccessible to P1 because it was instead positioned in P2's personal space. We found that the Unmatched P2 was on average more likely to interact with objects listed in any of the three instructions involving the red bell. However, Wilcoxon sign rank tests showed that only one of these results was significantly different from 50%. These results indicated that the player next to the target bell was on average consistently more likely to spend time trying to complete any tasks involving the target red bell, even though all these instructions were only provided to P1 (who necessarily communicated them to P2).

The instructions involving the purple bell were provided only to P2, but that target bell was located next to P1. The Unmatched P1 assumed the majority of responsibility for trying to complete any instructions involving the target

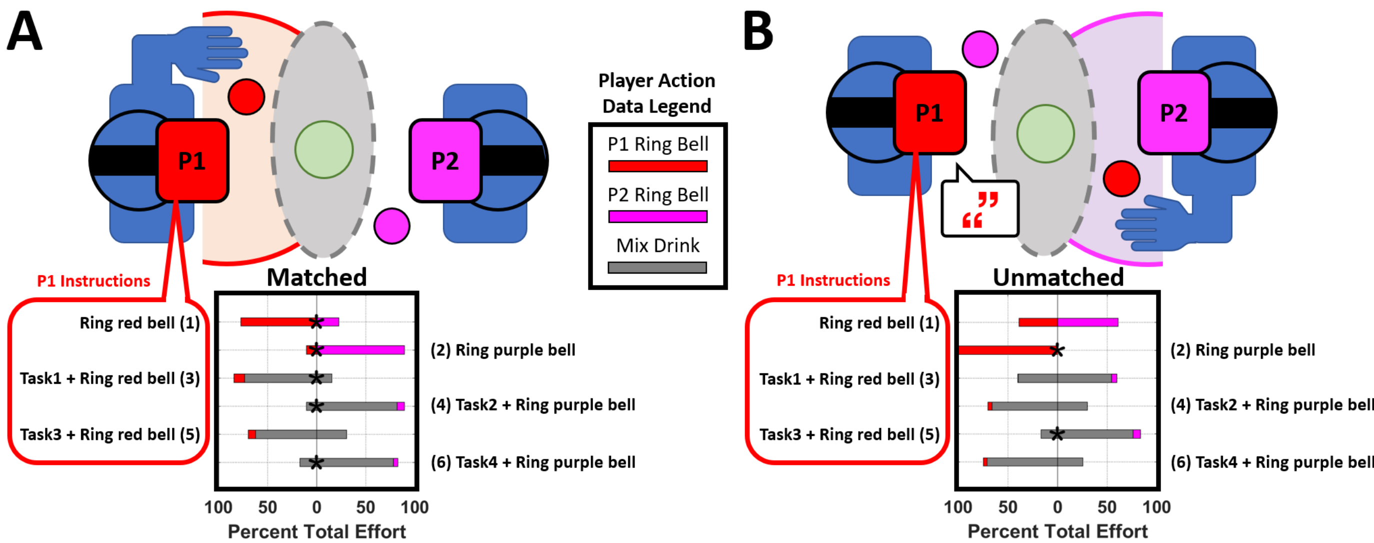

Fig. 5. Interaction strategy diagrams and corresponding average percent total effort data for players under each test condition. After the first two "practice levels" (in which both of the players located their respective bells), the players did not typically require much time or effort to repeat the bell ringing task. Consequently, the vast majority of the percent effort that each player provided in the final four levels was spent trying to interact with the novel objects in the shared play space. For both groups, the player with the target bell was consistently (i.e., for each instruction) on average more likely to complete tasks in the shared space. However, the Matched group (A) developed consistent (i.e., statistically significant) interaction strategies for more instructions than the Unmatched group (B). Error bars are not shown, but total effort SDs are provided in Table I. The total length of the bar(s) on either side of the zero mark represents the group average for a player's percent total effort, where the total bar length for both players together always equals 100%. Levels in which either player on average spent significantly more than half the total effort are marked as $* < 0.05$. Significance is determined using Wilcoxon sign rank tests.

purple bell, complementing the results witnessed for their partner (P2) on the red bell tasks. However, Wilcoxon sign rank tests again revealed that only one of these results was significantly different from 50%. Altogether, the results from the participants in the Unmatched group indicated that the player with physical access to the target bell was more likely to try to complete any instructions that included that bell, even though they did not have direct access to those instructions.

E. Group Comparison of Interaction Strategies

Switching the position of the bells was the only difference between the Matched and Unmatched game design conditions. To determine whether P1's interaction strategy for this task changed along with the position of the bell, we compared P1's percent total effort between the two test conditions. A series of Wilcoxon rank sum tests revealed that the percent total effort that P1 spent for each of the six instructions was significantly different between the two test conditions (Table I; all p<0.05 significance level). Overall, these group comparison results indicated that players' interaction strategies were consistently significantly different between the two test conditions.

VI. Discussion and Design Implications

A growing variety of tangible games have been shown to benefit spatial reasoning and learning by leveraging theories of embodied interaction [6], [18]. The vast majority of these studies demonstrate a diverse range of advantages tangible games can offer compared to more traditional interactive formats, but there are comparatively few experiments exploring how the finer aspects of a system can be designed to encourage specific interactive behaviors—especially collaboration. This

TABLE I
Mean and standard deviations for group average percent total effort provided by P1, with significant differences based on Wilcoxon sign rank (50%) or rank sum tests (Sig).

	P1 Percent Total Effort						
	Matched			*Unmatched*			*Sig*
Instruction	μ	σ	*50%*	μ	σ	*50%*	*p*
1-P1: *Red bell*	77	29	**0.03**	39	36	0.55	**0.03**
2-P2: *Purple bell*	11	22	**0.008**	100	0	**0.02**	**0.0002**
3-P1: *Task1 + Red bell*	84	30	**0.03**	40	43	0.36	**0.03**
4-P2: *Task2 + Purple bell*	11	29	**0.008**	70	40	0.11	**0.001**
5-P1: *Task3 + Red bell*	70	37	0.12	17	29	**0.03**	**0.02**
6-P2: *Task4 + Purple bell*	17	35	**0.02**	75	35	0.08	**0.002**

paper establishes empirical evidence to support prior claims of the importance of spatial design to implicitly encourage collaborative interactions through embodied facilitation [14].

Max Mixologist does not provide any explicit restrictions to indicate which player(s) should complete the tasks listed in each instruction. Aside from the game's design imposing digital and physical personal spaces (i.e., exclusive access to an instruction and/or target bell, respectively), the players had complete freedom of choice in their interaction strategies. Ultimately, we observed that the novelty of the game's swapped perspective design made physical collaboration (i.e., simultaneous execution of any tasks located in the shared space) especially challenging, which resulted in the players from both test groups typically developing variations of "turn-based" interaction strategies. Due to these game design features, we expected embodied facilitation to implicitly guide players' interactions with the objects and with each other. We compared interaction strategies that resulted from two versions of the game that were identical except for swapping the positions of the two bells. For the Matched condition, the exclusively accessible resources were only afforded to one player at a time (i.e., the instruction AND target bell). For the Unmatched condition, both of the players had exclusive access to only one of these resources at a time (i.e., the instruction OR target bell). Using this experimental design, we tested two hypotheses:

- Hypothesis 1: Distributing the exclusively accessible resources between the players would encourage more interpersonal collaboration.
- Hypothesis 2: Concentrating the exclusively accessible resources to one player at a time would result in more consistent interaction strategies.

A. Distributing Exclusive Resources Facilitates Collaboration

In the Matched group, the game afforded exclusive access to both the instructions and the target bell for only one of the players at a time (see Figure 5A). For the first two instructions that only involved bell-ringing, each player was informed to execute a task that only they could complete. In this way, the game's design set a standard by implying to the players that they were not required to involve their partner to complete "their" instructions. Correspondingly, both Matched players overwhelmingly opted to continue this trend in subsequent instructions by taking responsibility for any tasks that were paired with their nearby bell, even though those extra tasks were located in the shared space that was accessible to both players. In contrast, each of the Unmatched players always either had access to only the instruction or the target bell (see Figure 5B). This design meant that the game always required the players to communicate at least part of their instructions (i.e., bell ringing tasks) to their partner. Similar to the Matched group, we found that the Unmatched players most often opted to take responsibility for completing any tasks in the shared space that were paired with the bell in their personal space. In other words, even though the player receiving the instruction could have opted to complete the task in the shared space, they tended to inform/allow their partner to do it instead. These group trends indicate that the first two bell-ringing practice levels "trained" both players to develop interaction strategies that persisted for the remainder of the game. While speech data was not reported in this study, these interaction strategy results overall indicate that the Unmatched players engaged in a greater level of interpersonal collaboration via communicating instructions to the other player.

B. Concentrating Exclusive Resources Facilitates Consistent Interaction Strategies

Regardless of the test condition, our results strongly indicated that whichever player had access to the bell specified in the instruction was consistently (i.e., for every instruction) on average more likely to provide effort to complete the entire instruction (see Figure 5). However, this trend was almost always statistically significant for the Matched group, and almost never so for the Unmatched group. Since both groups tended to play the game in a turn-based fashion, these results indicate that the Unmatched players were more likely to divide execution of tasks for each instruction. More specifically, the Unmatched player with the instruction would occasionally opt to complete the drink mixing task in the shared space, and then their partner would finish the instruction by ringing the bell. Ultimately, distributing the exclusive resources between the players afforded greater ambiguity over which player should take responsibility for tasks in the shared space. In comparison, the Matched players with the instruction were more likely to complete tasks in the shared space, so they consequently demonstrated a more consistent interaction strategy both within and across individual games.

C. Design Implications

It can be difficult to generalize results between tangible game designs because of the diverse possible design choices and combinations of digital and physical elements [18]. However, this paper is relevant for tangible games that incorporate multiple resources that are exclusively accessible to one player at a time (e.g., a tabletop game with physical and digital elements). This group comparison study offers an example showing how distributing exclusively accessible resources, whether real or digital, across multiple players can encourage more collaboration between players. By extension, increasing collaboration through embodied facilitation can also afford players greater freedom of interpretation over how to collaborate, which can lead to greater variability in their chosen interaction strategies. When creating a tangible game with exclusively accessible components, designers should take care to understand how the distribution of exclusively accessible resources between players can implicitly guide their natural tendencies to both communicate and physically collaborate.

D. Study Limitations

The consistency of the interaction strategies witnessed in this study indicate that the observed turn-based patterns are most likely real and not due to chance. Even so, it is important to note that the sample sizes used in this study are small (less than 10 games in each group), and the number of games sampled for each group are not equal (although close). Additionally, a mixed-method approach (i.e., interviewing players about their experience) would have further bolstered our quantitative analysis.

E. Future Work

Future work will include testing further interactions with embodied facilitation, including modulating the location of objects in either the shared or personal spaces. For example, additional object configuration conditions can include making the bells equidistant from both players or, alternatively, placing some of the drink mixing objects within personal spaces. We are also interested in statistically evaluating social aspects of play. Comparing the amount of verbal communication between groups would better indicate how object placement impacts players' social (rather than just physical) interaction strategies.

VII. Conclusion

When playful collaboration is desired, tangible game designers can utilize principles of embodied facilitation to purposefully shape both physical and interpersonal interaction strategies. The results of this group comparison study provide an explicit example of how embodied facilitation can implicitly guide both physical and interpersonal interaction strategies within the context of a collaborative tangible game. Our results highlight how making a subtle change in the spatial configuration of exclusively accessible objects in a tangible game environment can cause players to naturally adopt widely different interaction strategies. This work provides implications for the importance of considering spatial design in a tangible game environment and the potential of such choices to drastically impact collaborative behaviors.

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