# Handoff and Deposit: Designing Temporal Coordination in Cross-Device Transfer Techniques for Mixed-Focus Collaboration

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## ABSTRACT

When working together, people frequently share information with each other to enable division of labour, assistance, and delegation of responsibility. The literature has explored both synchronous and asynchronous transfer techniques, known as Handoff and Deposit, respectively. However, current cross-device environments tend to only provide a single mechanism. Moreover, we have little understanding of the impact of different techniques on collaborative process. To understand how Handoff and Deposit may be designed to support complex sensemaking tasks, we followed a Research through Design process to iteratively design Handoff and Deposit techniques using paper and digital sketches and high-fidelity prototypes. We consulted the HCI literature to corroborate our findings with studies and descriptions of existing cross-device transfer designs and to understand the potential impact of those designs on mixed-focus collaboration. We learned that as we move away from a restricted physical workspace and leverage the flexibility of digital personal devices, there is a large design space for realizing cross-device transfer. To inform these designs, we provide five design considerations for cross-device transfer techniques: Transfer Acceptance, Action Dependencies, Immediate Usability, Interruption Potential, and Connection Actions.

### CCS CONCEPTS

• Human-centered computing~Human computer interaction (HCI)~Interaction techniques • Human-centered computing~Collaborative and social computing~Collaborative and social computing theory, concepts and paradigms~Computer supported cooperative work • Human-centered computing~Ubiquitous and mobile computing

**KEYWORDS:** collaboration, mechanics of collaboration, cross-device environments, cross-device interaction techniques, cross-device transfer, research through design

## 1 INTRODUCTION

Pinelle et al.'s [31] seminal research introducing the *mechanics of collaboration* describes two fundamental "mechanics" that collaborators use to transfer task materials, resources, and tools when working together: Handoff and Deposit. Handoff is a synchronous transfer act, like the physical act of handing a piece of paper to a partner. Deposit is an asynchronous act, like leaving the paper on a table for the partner to pick up later at their convenience. These mechanics serve distinct purposes in collaborative activities, like getting a partner's immediate attention versus asking them to review a document later on [31]. They are used to coordinate a transfer temporally, such as through a sequence of actions, as well as spatially, such as when placing an object near to a collaborator [48]. Providing different transfer mechanisms in a shared workspace gives collaborators freedom to use contextual factors, such as their current activity, task requirements, or the group's collaboration style to decide how to share task materials with one another in the moment [24,31].

Yet, prior research in Human Computer Interaction (HCI) has largely focused on providing a single transfer technique in a given multi-display environment (e.g., [1,30,55]). So, there is a lack of knowledge about how different transfer techniques impact collaborative processes. For example, if a system only supports Handoff, collaborators may experience frequent interruptions when transfer occurs, or they may hesitate to share data to avoid interfering with a collaborator's individual work. Whereas, if only Deposit is supported, transfer interactions may be more effortful than necessary during times when collaborators are engaged in ongoing discussions around shared content. Similarly, implementation details like how a transfer is initiated — such as when using a physical gesture [26,44] or picking and dropping content using a pen [36] — have also been shown to impact a group's ability to work together [1,10,17]. Such details are crucial in facilitating coordination in cross-device transfer. In particular, the impacts of design choices, like who is interrupted and to what degree, on collaborative processes are less understood by the HCI community, whereas spatial coordination has been widely studied following the theory of tabletop territoriality [40].

To investigate how the design and availability of different cross-device transfer techniques impact collaborative processes, we engaged in a series of design activities following a Research through Design process [8,58,59]. In particular, we designed cross-device transfer techniques within the context of a collaborative sensemaking task. Previous research shows that groups often perform sensemaking tasks in a mixed-focus fashion, comprising joint (tightly coupled) and independent (loosely coupled) work periods and transitions between them (e.g., [17,28,53]). We explored how temporal coordination of Handoff and Deposit can be designed to support mixed-focus collaboration through iterative design activities, observations of user sessions with design prototypes, and corroborating our findings with studies and descriptions of existing cross-device transfer designs and understand the potential impact of those designs on mixed-focus collaboration.

Five design considerations emerged through our research process that highlight key design choices that can impact mixed-focused collaboration during cross-device transfer: C1) transfer acceptance, C2) action dependencies, C3) immediate usability, C4) interruption potential, and C5) connection actions. In this paper, we document our Research through Design process, discuss the often nuanced implications of subtle changes to the design of transfer techniques, and report on how others can use this research to inform the design of cross-device transfer techniques in collaborative environments. The cross-device designs explored in this research were largely based on existing techniques; our emphasis was on understanding the impact of these designs on group work, especially involving mixed-focus collaboration.

In summary, our contributions are:

1. We problematize the impact of cross-device transfer techniques on collaborative process, and the need for more HCI research to explore flexible transfer techniques,
2. We present our Research through Design activities and design reflections on temporal coordination for a co-located collaborative sensemaking task, and
3. We identify five design considerations that can help researchers understand how temporal coordination supports or impedes joint and independent work periods and transitions between them.

## 2 BACKGROUND

In Pinelle et al.'s [31] description of the *mechanics of collaboration* transfer is defined as "the movement of objects and tools between people" [31:292]. They identified two distinct mechanics people use to transfer objects and tools in shared workspaces; Handoff and Deposit. Handoff occurs when one person transfers an item to another as a coordinated, synchronized action. In contrast, Deposit is an asynchronous action where one person leaves the item in the shared workspace where it can be retrieved later. In physical workspaces, an object's attributes are fixed and people can maintain awareness of others' interactions with the environment. Therefore, coordinating transfer requires little negotiation and often does not interfere with the task flow [48]. However, in computer-based workspaces, designers can control every aspect of where and what one can interact with and how data may be represented. Thus, cross-device transfer techniques have been widely explored by HCI researchers as they have developed more powerful and complex collaborative environments involving multiple displays (e.g., [26,33]). This freedom and flexibility can lead to novel techniques that enable new forms of interaction. However, research has shown that even subtle design decisions can impact collaborative processes [4,10].

Indeed, transfer techniques are deeply connected to the complex processes of communication and coordination, and when developing such techniques, designers navigate a myriad of trade-offs [17,41]. One such trade-off is the well-known tension between the needs of the individual and the needs of the group [10]; where individuals require independence and groups need awareness, coordination, and communication. A related design concern is how to best utilize the various displays available in cross-device environments during mixed-focus collaboration. Large-screen displays can act as shared reference points in collaborative activities and thus may be a suitable space to show shared data [53]. Personal devices, on the other hand, facilitate independent data exploration [17,27]. However, as people focus on personal devices for detailed data manipulation they may lose awareness of others' activities in the multi-display workspace [17,54]. It may also be disruptive to have one's partner pause their ongoing activity and attend to shared information.

Yet, we have little understanding of how the design and availability of cross-device transfer techniques ultimately impact collaborative processes. A multitude of transfer techniques have been introduced in the HCI literature (e.g., [26,43,55]; see [2] for a review) However, the literature has largely explored the use of transfer mechanics in isolation to each other — That is, either Handoff (e.g., [30,46]) or Deposit (e.g., [11,25]) is available, but rarely the two techniques at once. Notably, Marquardt et al. [25,26] and Ramos et al. [34] provided both Handoff and Deposit mechanisms in collaborative environments. However, neither research group studied how people employed the transfer techniques during anything beyond simplistic collaborative interactions.

In this work, we elucidate the connections between transfer techniques and collaborative processes. Through the iterative process of design, reflection, and observed user interactions of cross-device transfer techniques, we identify design considerations that help us understand how the user interface design of transfer techniques can facilitate temporal coordination of cross-device transfer and how various design choices may impact collaborative processes.

### 2.1 Coordination in Transfer Techniques

The mechanics of collaboration [31] highlight the high degree of both *spatial* and *temporal* coordination to facilitate object transfer in a shared workspace. Collaborators must agree on the timing of transfer and the location where it occurs. Spatial coordination concerns the use of physical and digital workspaces, and has been widely explored in work surrounding territoriality [40]. For instance, group members may use a distinct, "group" territory when sharing materials on a digital tabletop [40] or when working on a large wall display [52]. This use of space has been found to apply in many collaborative settings (e.g., [28,37,50]). Thus, mechanisms for spatial coordination have been widely explored in the literature, for both Handoff and Deposit techniques, such as portals [15,25,38], or partial or full views [11,26,56].

However, temporal coordination — the sequence of actions executed by the parties to complete the transfer or *the degree of synchronicity between the sender and the receiver* — is less understood. Many transfer techniques adopt a design pattern where a sender interrupts the person receiving shared information by requiring them to pause their ongoing work. For example, in Pick-and-Drop [15] the sender initiates the technique on their own device but must interact with the receiver's screen to finish the transfer. Other techniques automatically update the target display in a potentially disruptive manner. For instance, Face-to-Mirror [26], swiping [30,55], flicking [33,44], and pouring techniques [23] transfer a full screen or original-sized copy of the item. They do not require a receiver to confirm they are willing to accept shared information, but they do interrupt the receiver by pausing their individual work. These techniques explicitly synchronize collaborators which may be beneficial during tight collaboration. On the other hand, they may hinder independent work periods and transitions to joint work by forcing the receiver to pause ongoing work.

Conversely, other techniques need a lower degree of temporal coordination, by, for example, not requiring the receiver to attend to a shared item immediately. For instance, a portal on the target screen that receives a thumbnail of the shared item [1,25] or a partial view of the item that appears on the side of the receiving display [26]. Such designs give the receiver control over when to reposition and view the full item. Therefore, these techniques implicitly synchronize collaborators, promoting a stronger sense of freedom for the individuals but potentially at the expense of group awareness [10].

Existing frameworks for cross-device transfer cover interactions by the sender and receiver to execute transfer (e.g., [29,34]), though they do not provide guidance on how the specific degrees of synchronicity (described below) of a transfer technique may support or hinder collaborative processes. Nacenta et al. [29]'s framework categorizes cross-device transfer techniques based on various characteristics, such as: topology of the interaction space, reach range, and implicit privacy concerns. Other frameworks focus on the infrastructure for connecting devices together, for instance by using proxemics of people and devices, (e.g., [15,26,32,33]). Radle et al. [32] classified cross-device transfer techniques into three main categories: techniques that require both parties to perform synchronous gestures on their respective devices (this relates to our design consideration C2 (Action Dependencies)), techniques that leverage spatial positioning of devices in the environment, and techniques that do not rely on such information.

Our design considerations complement those frameworks by capturing the degree of synchronicity between the sender and receiver, and thus how a given cross-device transfer may foster or hinder tightly and loosely coupled work styles and transitions between them, whether or not the underlying environment is spatially aware or spatially agnostic. Moreover, the degrees of synchronicity provide a way to (1) categorize cross-device transfer techniques based on their impact on mixed-focus collaboration and (2) a language for researchers to articulate and understand the design space of cross-device transfer design.

### 2.2 Degrees of Synchronicity

We adapted a framework developed by Harris [12] to understand and articulate temporal coordination in multi-device environments. The original framework articulates the timing and duration of interaction between players in cooperative games. They define degrees of synchronicity that describe how in-game actions can be coordinated between players. We adapt the definition as "*the sequence of actions by the sender and receiver until the receiver can use the item without any further interaction with the interface*". Below are degrees of synchronicity for cross-device transfer, as adapted from Harris's original framework [12]:

1. *Instant* coordination occurs when the sender can both initiate and complete the transfer through their action(s) and the receiver does not have to interact with the interface before using the item. For instance, Face-to-Mirror [26] and Slam-to-Share [9] automatically update the target screen by displaying a shared picture in full-screen and original size, respectively.
2. *Expectant* coordination occurs when the sender initiates transfer, and are then held up until the receiver completes the transfer. For example, in Rhythmic tapping [45], two collaborators perform a sequence of actions to execute transfer.
3. *Sequential* coordination requires the sender to initiate transfer. The receiver then has a fixed amount of time to complete the transfer. For example, in Collaborative Handoff [23] and Stitch+Lift [34], the item is transferred to a portal on the target display and the sender must accept the item by repositioning it.
4. *Asynchronous* coordination occurs when the sender initiates transfer and some time later the receiver can attend to the transferred item to use it. For example, with Impromptu [1], a thumbnail of a shared window appears on a portal on the target device. It is then up to the receiver when to open the window and view the document.

We omit the *Coincident* and *Concurrent* degrees of Harris' original framework, as our research did not uncover any transfer techniques that used those degrees of synchronicity (i.e., sender and receiver performing actions at *exactly* the same time, either instantaneously or for some duration of time, respectively). Note, our degrees of synchronicity apply to the process of content transfer only. Actions required to connect devices to enable content transfer may require coincident or concurrent interactions, for instance, holding two devices together to enable content transfer between them (e.g., Bumping [13]) or Tilt-to-Preview [26]). We also added the *Instant* degree of synchronicity to account for transfer techniques that require no actions from the receiver to access or use transferred content.

In this work, we articulate how degree of synchronicity can inform the design of cross-device transfer techniques. In particular, we identify five design considerations that emerged as a part of our Research through Design process. These design considerations highlight the potential impact of a given temporal coordination design on collaborative processes. Our design considerations complement work by Ramos et al. [34] by offering insight on how any of the four choices of synchronicity in temporal coordination of transfer may impact the phases of mixed-focus collaboration.

## 3 METHODOLOGY

There is a lack of knowledge in HCI literature regarding the impact of cross-device transfer techniques on collaborative processes [17,18]. Even though Handoff and Deposit provide unique functions in supporting collaborators [31,48], existing work tends to provide only one mechanic of transfer in cross-device environments. Meanwhile, even subtle changes in the interface design could impact how people use technology to conduct group work [10]. Moreover, various factors impact group work around technology, like task settings and group dynamics [22]. We therefore decided on a Research through Design approach [8,59] to study this underexplored area, since it would enable us to:

- consider the conflicting needs of individuals and groups [10] that likely prevent an optimal solution for cross-device transfer,
- iteratively design, reflect, and reframe the problem as we develop an understanding of the design space, and
- identify questions that should be asked during the design process [58].

A key outcome of Research through Design is the documentation of our process [6,59]. This documentation increases our awareness [6] of how constraints shaped the design of our Handoff and Deposit techniques and impacted our design choices. For instance, we paid particular attention to how Handoff and Deposit actions may be temporally and spatially coordinated [48] in the system, and aimed to design transfer techniques to provide a reasonable balance between the needs of individual collaborators (i.e., freedom and power within the system) and the needs of the group (i.e., awareness of others' activities in the environment) [10]. Our designs were also inspired by the mechanics of collaboration [31] which describe how transfer takes place in physical shared workspaces. The documentation also provides information about discarded options given our research design context and, thus, could encourage exploratory research and reconsidering the opportunities that were filtered away in other contexts [6].

### 3.1 Design and Technology Contexts

We obtained access, with permission, to an existing experimental cross-device platform designed to support a mixed-focus sensemaking task for two people [17]. The experimental task involved joint analysis and decision-making around provided geospatial data. We re-architected the task to include a larger variety of information sources, and to encourage information sharing between two expert roles through a hidden profile task [47]. In this section, we only describe the configuration of the system and the features of the experimental task that are relevant to the research reported in this paper. Additional details about the system are provided in the supplementary materials.

The platform, which comprised a large interactive tabletop and two personal tablets, was designed to support a pair of collaborators seated at adjacent sides of the tabletop. The two tablets and the tabletop were configured to be automatically and by default connected through Wi-Fi. In this context, collaborators were trusted peers and had permission and authority to transfer data to each other's devices without any authentication actions. Our investigation focused on cross-device transfer between the tablet displays; transfer between the tabletop and tablet interfaces was left for future study.

## 4 RESEARCH THROUGH DESIGN ACTIVITIES

Our Research through Design process comprised three phases (Table 1). First, we developed low fidelity *paper and digital prototypes* with a focus on how they impede or support collaboration [8,58]. These prototypes allowed us to rapidly reflect on and critique our designs and consider their potential advantages and disadvantages, through discussion and feedback sessions with HCI experts and HCI trainees. Second, we developed *high-fidelity prototypes* that we used to explore the impact of our Handoff and Deposit techniques on mixed-focus collaboration. Third, we corroborated our findings with transfer techniques from the HCI literature to obtain a broader understanding of temporal coordination issues in cross-device transfer and the potential impact of degrees of synchronicity on collaborative processes.

We started designing Handoff and Deposit techniques based on the mechanics of collaboration [31]. Throughout our Research through Design process, we gained and developed an understanding of the theory's limitations when it comes to facilitating temporal coordination of Handoff and Deposit in our digital environment. Adapting Harris's framework [12] was helpful for us to better understand and articulate the constraints in our design research problem.

Table 1. Our Research through Design comprised 6 iterative design activities grouped into three phases based on instruments used. In each activity, we gained insights about designing Handoff and/or Deposit techniques to support mixed-focus collaboration. The outcome of each activity informed the next design activity. In each phase, our insights and outcomes led to design considerations for designing Handoff and Deposit.

| Instruments | Design activity | Insights | Outcomes | Design Considerations |
|---|---|---|---|---|
| Paper and digital sketches | 1. Handoff Design | Sender is held up in transfer to grab Receiver's attention | Designed Handoff with partial view | C1: Transfer Acceptance |
| | 2. Deposit Design | Portals support spatial coordination of transfer | Re-designed the tablet interface and a Deposit technique | C2: Action Dependencies |
| | 3. Handoff Alternative | The interface can grab Receiver's attention. So, Sender does not have to be held up | Designed Freeze-Handoff and refined the tablet interface | |
| High-fidelity prototypes | 4. User observations with Deposit and Freeze-Handoff | Freeze-Handoff was perceived as intrusive and thus was avoided | Designed Fullscreen-Handoff | C3: Immediate Usability |
| | 5. User observations with and Deposit and Fullscreen-Handoff | Showing data immediately to Receiver reduces collaborative effort | Found Deposit and Fullscreen-Handoff were both used, in different situations | C4: Interruption Potential |
| HCI literature | 6. Corroboration | Our design considerations impact the degree of synchronicity between Sender and Receiver | Created design considerations | C5: Connection Actions |

The cross-device transfer designs we created during the process of this research are based heavily on existing techniques from the literature in terms of their degrees of synchronicity. The user interface of our techniques, however, was different. The focus of our research was to better understand how the design features of these techniques support or hinder mixed-focus collaboration, and thus, we consider their impact on individual interactions, joint group interactions, and transitions from loosely coupled to tightly-coupled work periods.

### 4.1 Paper and Digital Sketches

We began by iteratively generating numerous designs for Handoff and Deposit using digital and paper sketches (Figure 1). The sketches facilitated communicating our designs to others and rapid design revisions at early stages of the research. Insights gained in this phase about who might be held up (sender and/or receiver) during transfer in mixed-focus collaboration led to the development of C1 (Transfer Acceptance) and C2 (Action Dependencies). These design considerations draw attention to interactions needed by the sender and/or receiver with the interface to perform a transfer.

**During our Initial Handoff Design** (Figure 1, Design Activity 1), we discussed the roles of the sender and receiver in Handoff and Deposit in a physical environment. We determined that temporal coordination in Deposit follows an Asynchronous pattern. It can also require fewer interactions compared to Handoff as the sender leaves the item somewhere in the environment for later retrieval by the receiver. However, Handoff has an Expectant degree of synchronicity; the sender is held up in Handoff as they hold an item and wait for the receiver to accept or reject it. This situation creates social pressure on the receiver for a timely response. Thus, our initial design idea for Handoff (Figure 1) was a technique that paused the ongoing work of the receiver and updated the display to show the transferred item. Design alternatives considered included showing a full screen or partial view of the item. We decided the latter was a more reasonable design choice as it did not invade the receiver's personal territory, similar to physical Handoff, which often occurs in a shared space rather than in personal territories [48]. This design is similar to Tilt-to-Preview [26], which requires the sender to tilt and touch an image so that a partial view is sent to the target screen. However, our technique did not rely on collaborators' devices being in close proximity nor being tilted to enable content transfer.

We felt this design provided a reasonable balance between the needs of the individual (the receiver) and the group (both sender and receiver). The partial view keeps the sender aware that part of the item is visible on the target screen, and it makes the receiver aware of the data transfer while not substantially changing their current view (reducing interference). Thus, the design had the potential to support loosely coupled work periods and shifts to tightly coupled work. However, our initial design discussions identified several factors related to temporal and spatial coordination of both Handoff and Deposit. For example, there were open questions related to the location of transferred items, the distinction between transfer techniques on home and target screens, and so on. Thus, we proceeded with a brainstorming session with people outside of our group to hear more diverse perspectives on designing a Deposit technique given the above factors impacting collaboration and given our initial Handoff design.

**For a Deposit Design** (Figure 1), we held a brainstorming session with three HCI trainees to gather ideas on how we could incorporate a Deposit technique into our tablet interface. The small group size allowed us to lead a focused discussion and hear from all participants. Our participants identified previous research that showed when people work around a table, they usually hesitate to take items from or put them in a partner's personal work space [37,40]. Also, people naturally avoid interfering with each other in shared spaces by spatially separating their work [51]. Therefore, we redesigned the tablet interface to have three distinct areas to support content sharing and independent work.

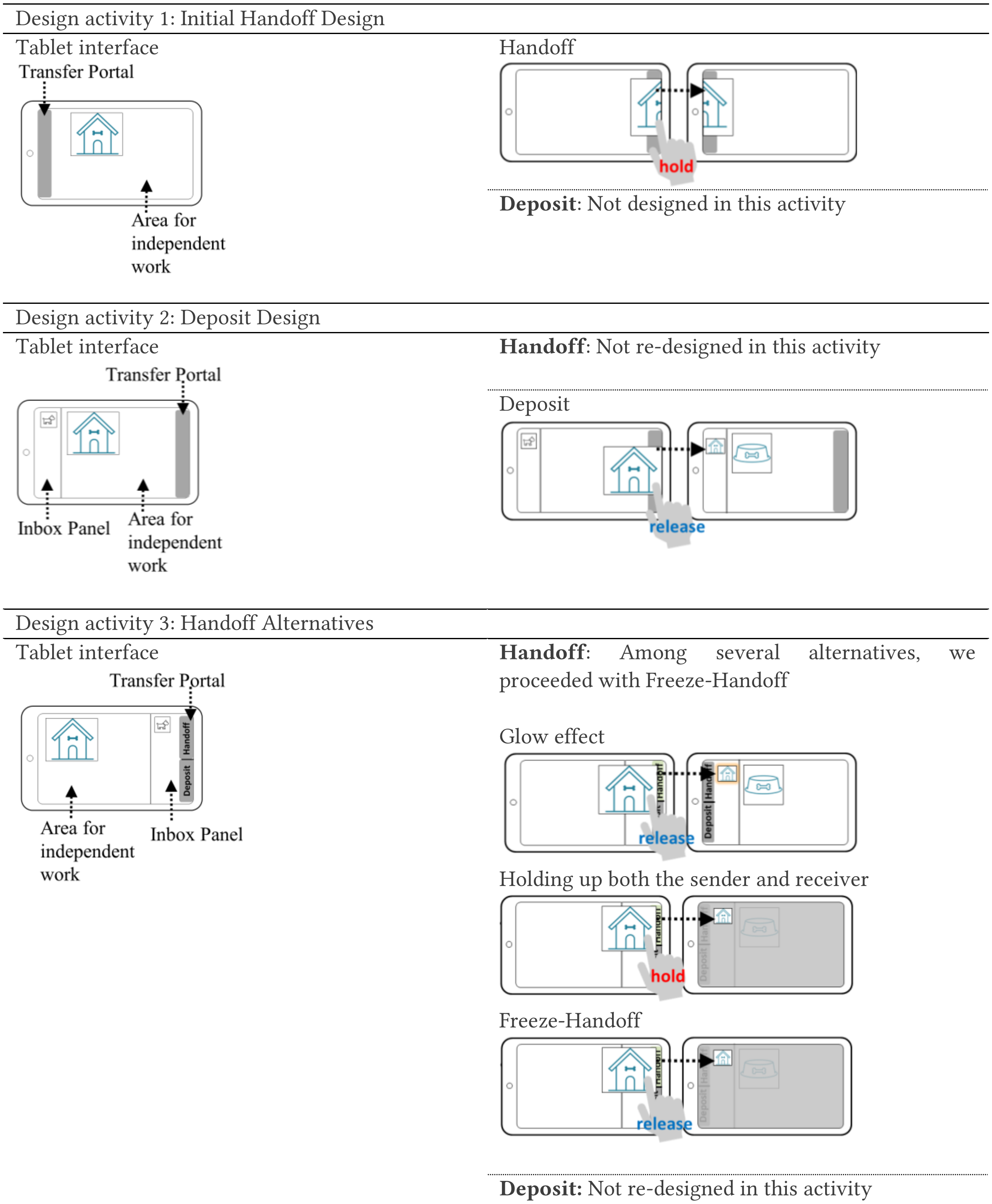



Figure 1. Our iterative design activities in Phase 1 using paper and digital sketches. The design of our tablet interface, and Handoff or Deposit techniques in each activity evolved as our framing of the design problem developed. For each activity, the resulting designs are illustrated. Note that in some activities, the design of Handoff or Deposit techniques did not change.

An inbox panel and a portal (Figure 1, Design Activity 2, Tablet interface) facilitated spatial coordination of cross-device transfer [48] similar to the idea of virtual portals [7,39]; a thumbnail of a shared item would appear on the panel in Deposit (Figure 1, Deposit Design). Other techniques such as Collaborative Handoff

[25] and some Cooperative Stitching Gestures [34] also send a thumbnail or notification to a portal on the target screen upon transfer. However, our Deposit technique did not impose a time limit nor require acceptance by the receiver. The technique synchronized the sender and receiver in an Asynchronous manner, as the receiver could retrieve the thumbnail at their convenience. We felt the Deposit design would foster independent work as it did not interfere with any ongoing interactions in the tablet's main workspace. The sender could also release the touch gesture and continue their ongoing work.

**To create Handoff Alternatives** (Figure 1), we first integrated our Initial Handoff design into the redesigned tablet interface and then presented it to another, larger group of two HCI experts and twenty HCI trainees for feedback on our design and to help generate ideas for potential Handoff design alternatives. An insight we gained through this activity was that in physical Handoff, the receiver could be held up as well as the sender. The receiver is aware their partner is waiting for a response. Social protocols could create pressure for them to react promptly. Therefore, it is important to consider whether the receiver may also be held up as they pause their ongoing work to accept or reject the shared item.

This insight led to the development of design considerations C1 (Transfer Acceptance) and C2 (Action Dependencies). Transfer Acceptance (C1) draws attention to whether transfer should be permitted by default or if the receiver must accept or reject the transfer. The latter design approach may be selected, for instance, if security and privacy are matters of concern in the expected usage context. Action Dependencies (C2) refers to whether the user interface holds up any party by requiring one or both to perform a series of actions to initiate and/or complete the transfer. A relevant context for C2 is where asymmetric roles exist, for instance a teacher-student relationship, and the sender wants to ensure the shared item is attended to immediately.

Following the insights that led to C1 and C2, we considered alternative Handoff designs that hold up the sender, receiver, or both. We drew inspiration from existing transfer techniques in terms of their degrees of synchronicity and considered them through the lens of the theory of mechanics of collaboration. For example, the Stitch+Hold [34] technique holds up the sender until the recipients accept the connection. Rhythmic Tapping [45] holds up both parties as they perform a series of gestures to establish a connection between devices. Similar to our Freeze-Handoff, AirDrop holds up the receiver and asks them to accept or reject the transfer when sending content to an iPhone with a different Apple ID. Our technique transfers a thumbnail of the item and then halts the screen until the receiver drags the item off their inbox panel. AirDrop, however, shows a pop-up window notifying the receiver of a pending transfer.

Careful reflection of those options revealed new insights on operationalizing the mechanics of collaboration in our *digital* workspace. The digital context enables us to get the receiver's attention and, thus, alleviate some effort on the sender's side. That is, it may not be necessary to hold up the sender. Although techniques that hold up the sender may be more consistent with people's mental model of how they transfer physical objects, we believed that in our peer collaboration context holding up the sender would be unnecessary and potentially effortful.

Given these trade-offs, we decided to proceed with a Handoff design that only holds up the receiver by potentially interrupting them (Figure 1, Freeze-Handoff). Freeze-Handoff adopts the Sequential degree of synchronicity; after the sender initiates the Handoff by placing an item on their "Handoff" portal, the receiver must move the thumbnail off their inbox panel into their main workspace to complete the transfer, and before they can either continue with any ongoing work in their main workspace or enlarge the transferred image to view it full-size. Thus, the receiver would be interrupted during independent work or transitions to joint work. However, we did not anticipate interruptions during joint work periods since the receiver would be expecting the transfer and the associated update to their screen.

At this point, we felt that our Handoff and Deposit transfer designs would provide flexible means for groups to share data in a mixed-focus collaboration context. Our design activities with our sketch-based prototypes indicated that our Deposit design would support loosely coupled work periods as it showed a thumbnail of the item but did not hold up the receiver—they could use the transferred item at their convenience. The Freeze-Handoff design would support tightly coupled work and transitions to tightly coupled work as it grabbed the attention of the receiver without covering their independent work area. Thus, we proceeded to develop high-fidelity prototypes to enable observation of user interactions with our techniques to help better understand how they supported or hindered collaboration and to facilitate further design refinement.

### 4.2 High-Fidelity Prototypes

We conducted two rounds of user observations (Figure 2Figure 2) involving four different pairs of collaborators (two per round) (5 male). The participants were between the ages of 20-45. Seven were graduate students; six in Engineering or HCI, one in Applied Health Sciences. One participant was a software engineer. Each pair used our high-fidelity prototypes to complete a collaborative sensemaking task in approximately 45 minutes. The pairs in the first round used Freeze-Handoff and Deposit techniques (Figure 2, Design activity 4). The pairs in the second round used Fullscreen-Handoff and Deposit techniques (Figure 2, Design activity 5). During each session, the first author and the software developer who implemented our prototypes observed the sessions and took notes. At the end of each session, the first author conducted an informal interview to further understand participant behaviour. In all four sessions, groups completed the experimental task using a mix of joint and independent work periods, dominated by long periods of joint work. We elaborate further on these activities below.

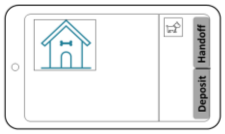
**In our User observations with Deposit and Freeze-Handoff**, to our surprise, participants hesitated to use Freeze-Handoff, even during tightly coupled joint work periods, when we expected this technique to be used. The interviews revealed that participants perceived the technique as intrusive. They reported that they did not want to force the receiver to pause their ongoing work to attend to the transferred data. We carefully reflected on how Freeze-Handoff placed responsibility for temporal coordination on the sender: Freeze-Handoff automatically interrupts the receiver by halting their screen and highlighting the thumbnail in their inbox panel. While in a physical environment, Handoff is likely to be quickly received due to social pressure on the receiver, there is also some flexibility in the timing of when the receiver must accept it. In Freeze-Handoff, however, the interface did not allow such flexibility: as soon as the sender completed the interaction, the receiver's screen was interrupted, and the only possible action was dragging the thumbnail off the inbox panel to the independent work area of the screen.

Since Freeze-Handoff was avoided, our participants used Deposit to achieve the intended goal of "Handoff", that is, in situations when the receiver immediately attends to the transferred item. However, when Deposit was used during tightly coupled work, a group's conversation was often disrupted while the receiver moved the data item off the inbox panel to their independent work area and then enlarged it to view its details. This disruption made the Deposit technique effortful for the group during tightly coupled work periods.

The above observations led us to reconsider a design alternative disregarded in our Initial Handoff Design: transferring a full-screen version of the item in Handoff. In this design approach, the ongoing work of the receiver is still interrupted (like Freeze-Handoff). However, there is a benefit that potentially mitigates the interruption in transitions to joint work: the group can immediately start a discussion around the data without the receiver needing to move and/or enlarge a shared image to a legible size. Moreover, when transfer occurs as part of ongoing tightly coupled work, the receiver can immediately view the details of the shared data without having to first enlarge it. These insights led to the third design consideration C3 (Interruption Potential), which describes the potential benefits and drawbacks of automatically interrupting the receiver.

Design activity 4: User observations with Deposit and Freeze-Handoff

Tablet interface*



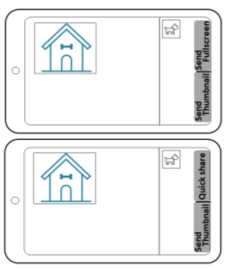

Freeze-Handoff*


Deposit*


*These designs did not change in this activity. They are the same designs as in Activity 3 (Figure 1). The pictures are placed in this figure for easier readability.

Design activity 5: User observations with Deposit and Fullscreen-Handoff

Tablet interface




Fullscreen-Handoff


**Deposit**: Not redesigned for this activity (remained the same as Deposit in Activity 4)

Figure 2. Our iterative design activities in Phase 2 using high fidelity prototypes. The tablet interface, Handoff and Deposit techniques in each prototype are illustrated. Note that our Deposit technique remained the same for both activities.

Therefore, we revised Freeze-Handoff to immediately show data full-size on the receiver's workspace. We called this design alternative Fullscreen-Handoff (Figure 2). Other techniques that transfer a full-size copy of the item include Face-to-Mirror [26] and Slam-to-Share [9]. Our technique differed from those in that it grayed out the tablet screen and then showed the enlarged item. Based on participant use of Deposit in the first round of observations, we predicted that Fullscreen-Handoff would support the flow of an ongoing discussion and, thus, joint work periods in mixed-focus collaboration. Fullscreen-Handoff synchronizes the sender and receiver in an Instant manner; as soon as the sender completes transfer on their side, the system shows the item in full screen on the target device without the need for further interactions by the receiver.

**In our User observations with Deposit and Fullscreen-Handoff,** the system incorporated Fullscreen-Handoff (Figure 2, Design Activity 5). In the first user session, we labelled Handoff as "Quick Share" and Deposit as "Send thumbnail". We observed that the group used Fullscreen-Handoff more frequently than Deposit. We were concerned that the name "Quick share" might have biased people to use the technique more frequently. Thus, before the second session, we renamed Handoff to be "Send fullscreen" to more accurately describe its function (Figure 2, Design activity 5, Tablet interface). Even with this change, participants in the second session still used Handoff more often than Deposit, providing us more confidence that use of this feature was not likely biased by the label.

As we predicted, Fullscreen-Handoff was used during joint work periods, especially when groups discussed specific solutions and data. In such cases, the receiver would sometimes ask their partner to send data using the full screen option. The fact that the image was immediately usable, i.e., large enough for the image/graph details to be legible, afforded an effective conversational flow. In other words, the design supported tightly coupled work periods by displaying the content immediately and without further need to interact with the user interface. Conversely, Deposit allowed participants to respect the ongoing work of their partners by only sending a thumbnail of the item to avoid disrupting ongoing work. Thus, as we expected, people used Deposit primarily during independent work periods.

These observations led to the development of our fourth design consideration C4 (Immediate Usability). This design consideration provides insights on how joint work periods may be facilitated by making a transferred item readily usable upon transfer and, thereby, reducing disruption —and potentially the collective effort—during the transfer process.

## 5 DISCUSSION AND CORROBORATION WITH THE LITERATURE

As the final activity in our Research through Design process, we reviewed prior studies and descriptions of existing cross-device transfer designs from the HCI literature to corroborate our design considerations and understand the potential impact of those designs on mixed-focus collaboration. This activity provided a broader perspective on how our design considerations might apply to transfer techniques beyond those we studied in the Research through Design activity. Our goal was to identify potential inconsistencies with design issues discussed in the literature and uncover any gaps in our design considerations that might be highlighted by design features of other transfer techniques. Through this process we mapped our design considerations to existing techniques from the literature (Table 2), and in doing so, discovered a need for an additional design consideration related to connectivity in multi-device environments.

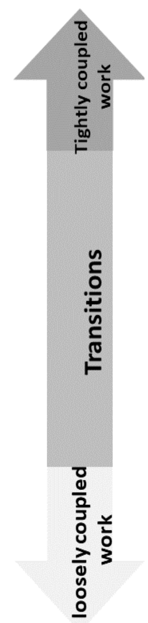
This corroboration activity led us to adapt Harris's [12] framework to understand and articulate the degree of synchronicity between collaborators in cross-device transfer, and to include a design consideration around the Connection Actions (C5) required to establish a multi-device environment. As Brudy et al. [2] point out, cross-device interaction techniques could have a connection establishment phase to prepare and authorize devices for content transfer. Researchers have identified a broad array of such actions, including explicit interactions with the interface or both devices [13,29,49], implicit actions such as taking a device out of a pocket [29], explicit movement of devices in the environment [25,26,29,32], and authorizing a technique to transfer content to the receiving device [1,34]. This design consideration was not apparent in our Research through Design process, as devices in our high-fidelity prototype maintained a permanent, trusted connection upon application start-up. Synthesizing our work with the literature allowed us to explore a wider variety of device capabilities and task and user requirements. Connection actions are a useful consideration in designing transfer techniques where privacy concerns exist. Design details such as revealing content that can be shared or devices that are available for connection might encourage data sharing [25,34].

Our corroboration activity also enabled us to reflect on and refine our definitions for each design consideration, to consider how different techniques from the literature have implemented different design concepts within the design space, and how those design choices ultimately impact the degree of synchronicity of collaborative processes.

### 5.1 Design Considerations for Temporal Coordination in Cross-Device Transfer

We identified five design considerations that articulate how one may support temporal coordination when designing a cross-device transfer technique (Table 2). The design considerations draw attention to how specific design choices in the interface design of a transfer technique may impact the way people use technology during mixed-focus collaboration. The way a given transfer technique addresses each design consideration creates a certain degree of synchronicity, which can help HCI researchers and practitioners predict how a cross-device transfer technique may affect collaborative processes.

Table 2. Design considerations for temporal coordination in cross-device transfer techniques. Our corroboration with the HCI literature revealed a gap, which led to C5 and adaptation of a framework [12] for articulating the degree of synchronicity in cross-device transfer. Our Deposit and Handoff techniques and some representative techniques are shown with respect to how they address C1-C5, their degree of synchronicity and their likely impact on mixed-focus collaboration.

| | Design Considerations | | | | | | |
|---|---|---|---|---|---|---|---|
| Example Techniques | C1: Transfer Acceptance | C2: Action Dependencies | C3: Immediate usability | C4: Interruption Potential | C5: Connection Actions | Degree of synchronicity | Likely to support |
| Fullscreen Handoff (Figure 2), Slam-to-Share [9], Flicking [33,44], Superflick [35] | | | • | • | | Instant |  |
| Bumping [13,14], Smart-Its Friends [16], ConnecTable [49], Pick-Drag-and-Drop [33] | | | • | • | • | Instant | |
| Face-to-Mirror [26] | optional | • | • | • | • | Instant | |
| Rhythmic tapping [45] | • | • | | | | Expectant | |
| Tilt-to-preview [26], | optional | • | | | • | Expectant | |
| Stitch+Hold [34] | • | • | | | • | Expectant | |
| Stitch+Lift [34], Broadcasting-cues [11], Corresponding gestures [29], PicknDrop, Menu [57] | • | | | | | Sequential | |
| AirDrop* (when sending content to iMac or MacBook with a different Apple ID), Collaborative Handoff [25] | • | | | | • | Sequential | |
| Portals [26], IMPROMPTU [1], Our revised Deposit (Figure 2), Portfolio [3], Tray [57] | | | | | | Asynchronous | |
| Freeze-Handoff (Figure 2) | | | | • | | Sequential | Was found ineffective |
| AirDrop* (when sending content to an iPhone with a different Apple ID) | • | | | • | • | Sequential | Likely to be ineffective |

*: AirDrop sends a non-blocking notification to iMac and MacBook devices, whereas notifications sent to an iPhone block the receiver from interacting with other parts of screen.

### *C1: Transfer Acceptance*

It is important to consider whether a transfer technique requires the receiver to explicitly accept an item before it is transferred to their device. Designers should use the expected collaborative context to guide this decision. For example, if trust and privacy are of key concern, the receiver could be required to explicitly permit the transfer to occur [5,29,34]. In this case, the target device could temporarily receive the item and notify the receiver (e.g., [25]). In our peer collaboration context, we assumed that parties are permitted [34] to transfer content to each other's devices. Therefore, our Freeze-Handoff, Deposit, and Fullscreen-Handoff designs all allowed the system to automatically accept the transfer. In other cases, it may be appropriate to have explicit steps to enable this "trusted" status for the duration of the collaborative session (in conjunction with Connection Actions (C5)).

### *C2: Action Dependencies*

It is also important to consider whether a sender or receiver must await the other's actions during transfer. In physical workspaces, a sender simply needs to decide between a (synchronous) Handoff and (asynchronous) Deposit [31]. Digital workspaces afford a wider array of potential designs that may or may not require explicit synchronization between the sender and receiver [29,34]. For example, in a classroom setting, a teacher may want to ensure that items sent to students are attended to promptly. Whereas in contexts like collaborative sensemaking where there are periods in which collaborators work independently, it may be inappropriate to hold up a collaborator and, thus, an asynchronous transfer may be more appropriate.

*C3: Immediate Usability*

This design consideration refers to whether the receiver can use the transferred item with no further interface interactions, e.g., opening a file, enlarging or repositioning an image. Immediate usability may or may not be desirable, depending on the task context. For instance, when transitioning from loosely coupled to tightly coupled work, showing an enlarged version of the shared item may be disruptive to ongoing independent work. Scott et al. [39] assert that designing the *post-transfer state* of shared content is highly dependent on contextual factors, such as the task requirements. Our research showed that displaying the shared item in an immediately usable format during joint work periods was advantageous for the collaboration flow. Indeed, some participants in our user sessions asked their partner to share content in full screen format to facilitate ongoing conversations and joint analysis.

In other situations, some participants chose Fullscreen-Handoff transfer over Deposit to send data during joint discussions to assist the receiver in immediately viewing the data. Such assistive behaviour fosters communication grounding [18] and facilitates tightly coupled work [17,20]. Given the potentially disruptive nature of automatically displaying a large item on the receiver's screen, this design consideration should be considered in concert with C4 (Interruption Potential). The trade-offs of a given transfer design being helpful in some moments and potentially disruptive in others suggests the benefit of providing flexible transfer techniques in collaborative multi-device environments, similar to physical shared workspaces in which people can use different transfer mechanics [31].

*C4: Interruption Potential*

It is also important to consider whether a transfer technique has the potential to interrupt a receiver's ongoing, independent work, and whether that is desirable. Many existing cross-device transfer techniques such as Face-to-Mirror [26], Pick-Drag-Drop [33], and Slam-to-Share [9] adopt a pattern where the receiver is automatically interrupted upon transfer. Whether such interruptions are appropriate highly depends on the context and flow of the collaborative activity. Interrupting the receiver's ongoing work by automatically opening a transferred item in their main workspace might disrupt important work [17,18], and require them to cognitively reorient to the new work context. On the other hand, it might minimize overall interaction effort for a group already engaged in tightly coupled work. In some contexts, it might be sufficient for the sender to time the interruption using social protocols.

*C5: Connection Actions*

Collaborators may enable cross-device transfer in a number of different ways [2]. For instance, Bumping [13] and ConnecTable [49] require collaborators to place their devices physically together to enable cross-device transfer. On the other hand, proxemics-based techniques might only require devices to be nearby, in the same social or conceptual space (e.g., [25,33,42]). Whereas techniques like our high-fidelity prototypes may rely upon a connection being established once at the beginning of a collaborative session, and then rely on virtual interfaces like portals to facilitate transfer. Requiring explicit connection actions before a transfer can be initiated adds additional time and effort to the transfer process and, thus, will likely be disruptive to ongoing, tightly coupled work. Minimizing such connection actions, even temporarily, in contexts when multiple transfers may be desired during periods of tightly coupled work would help to facilitate collaboration.

## 5.2 Impact of Degrees of Synchronicity on Collaboration

As part of our corroboration activity, we found that examining the degree of synchronicity of different transfer techniques helped to identify the phases of mixed-focused collaboration they were most likely to support. The degrees of synchronicity are four ordinal values for grouping cross-device transfer techniques. Notably, they also provide a vocabulary to talk about the impact of given techniques on collaborative processes. Further, our corroboration activity helped reveal how different techniques might complement each other and what shortcomings they may have for transferring content across personal devices. Mapping transfer techniques to degrees of synchronicity (Table 2) provides a vocabulary for communicating the likely impact of a given technique or set of techniques on the different phases of mixed-focus collaboration.

Transfer techniques that utilize Instant synchronicity enable the transferred item to be readily usable (C3, Immediate Usability) without the need for further interactions on the target display. Thus, such techniques are likely to support active discussions during tightly coupled work [17,18]. Note that any technique with Instant synchronicity would check off C3 in Table 2. However, it would not necessarily have Interruption Potential (C4). Consider the case of sharing audio content. Playing an audio on the target device does not have to update the screen and, thus, the receiver could carry on with independent visual work while listening to the audio. Another example would be sharing small images like icons that could open in a way that do not block the work area of the receiver.

Cross-device transfer techniques that adopt an Asynchronous pattern are likely better suited to supporting loosely coupled work periods in mixed-focus collaboration. Previous research has found that interaction techniques that give individuals freedom to perform their tasks without having to depend on or interrupt their partner facilitate loosely coupled work [17,21]. Techniques with Asynchronous synchronicity give the receiver the power to complete, or pause, their current task before attending to the transferred data.

Techniques that adopt Expectant or Sequential synchronicity are likely to support transitions to loosely coupled work periods. Such techniques can be designed in a way that do not interrupt the independent work of the receiver and allow them to develop awareness of the transfer. Thus, the receiver can quickly wrap up their work and then attend to the transfer. With Expectant synchronicity, there is social pressure on the receiver (since the sender awaits their response) and therefore, they may feel pressure to respond quickly. Therefore, we believe techniques adopting Expectant synchronicity (e.g., Stitch-and-Hold [34] and Tilt-to-Preview [26]) are closer to 'Likely to support tightly coupled work' compared to those adopting Sequential synchronicity (e.g., Collaborative Handoff [25] and Corresponding Gestures [29]), in which the receiver has a predefined, and reasonable, amount of time to react to the transfer. Since the sender is not held up waiting for the receiver the complete the transfer with Sequential synchronicity, they are free to return to independent work, as desired. So, these techniques are closer to 'Likely to support loosely coupled work'.

## 6 REFLECTIONS ON OUR RESEARCH THROUGH DESIGN PROCESS

Criteria for contributions made by a Research through Design approach are rigor in process, novelty, relevance, and extensibility [19,59]. Regarding **rigor**, we documented our research process by describing the methods applied, the rationale behind our choices, and how our design considerations emerged in our investigations. We described some alternative Handoff designs that were filtered away due to our research context and goals but that could be pursued by ourselves or other researchers in the future. For instance, Handoff with a glow effect (Figure 1)fi is likely to grab the receiver's attention in a subtle way without interrupting their screen and thus may facilitate transitions to joint work periods. However, our goal was to explore techniques closer to the original Handoff described in the theory of mechanics of collaboration, which involved holding up a party during transfer. Our work builds on exiting theory and HCI research asserting the importance of interface design on how people conduct group work around technology (e.g., [17,18,21,31]).

Throughout our research process, we investigated how the mechanics of collaboration [31] could be operationalized in our digital environment to facilitate transfer for mixed-focus collaboration. The theory was useful in identifying gaps in the literature with respect to flexible transfer techniques in collaborative environments, and for guiding our designs based on transfer in physical workspaces. However, we found a broader range of useful design criteria for our digital environment than the theory implies. In our corroboration activity, we identified and adapted Harris's framework [12] that helped us better understand and articulate the constraints and nuances of temporal coordination between the sender and receiver, and thus their degree of synchronicity.

Our exploration of the under-studied question of how temporal coordination affects cross-device transfer techniques on collaborative processes produced **novel** insights, including our design considerations, the degree of synchronicity between collaborators, and the likely impact of transfer design choices on mixed-focus collaboration. Our design considerations can be used alongside existing frameworks to establish connections between devices, such as proxemic-based techniques [9,26,33].

Regarding **relevance**, we contribute knowledge that problematizes the impact of cross-device transfer designs on mixed-focus collaboration. We articulate that design details such as how a transfer is initiated or who is interrupted and to what degree are crucial when building interfaces that facilitate work involving joint and independent work styles and shifts between them. We based our argument on our own findings and previous HCI research.

Our contributions have analytical and generative potential thus the knowledge that we contribute is **extensible**. We hope that HCI researchers and technology designers will adopt our design considerations to inspire designs that deeply consider the impact of cross-device transfer technique on collaborative processes to improve the ability of multi-display environments to support complex collaboration. Our design considerations can also be used analytically to understand how existing designs might be employed in mixed-focus collaborative contexts.

## 7 CONCLUSION & LIMITATIONS

Our research through design process highlights a need for the HCI community to more deeply explore how the design and choice of cross-device transfer techniques impact collaborative processes. The Handoff and Deposit mechanics of transfer serve different purposes in collaboration. Thus, they provide collaborators flexible transfer options that suit the ongoing flow of group work. Our findings suggest that designers should tailor the transfer techniques within a cross-surface environment to support both independent and joint work periods and shifts between them.

To enable designers to provide appropriate support, we developed five design considerations that incorporate degrees of synchronicity [12] to describe how different design choices of temporal coordination might influence a group's collaborative process. Our Research through Design process enabled us to iteratively design and evaluate Handoff and Deposit techniques, and to derive five design considerations that help articulate how certain design choices for cross-device transfer techniques may affect individual or collaborative behaviour in mixed-focus collaboration: Transfer Acceptance, Action Dependencies, Immediate Usability, Interruption Potential, and Connection Actions. These design considerations provide guidance for early design stages and for evaluating existing cross-device transfer techniques. They provide a vocabulary for further work that investigates the impact of cross-device transfer techniques on phases of mixed-focus collaboration.

As a single study, we also acknowledge limitations of our work. Although cross-device environments may facilitate content sharing between personal and shared devices, we focused on supporting content transfer across personal displays, and specifically across tablets. Future work can build on our findings to investigate other cross-device configurations, such as tablet to tabletop/wall or tabletop/wall to tablet transfers. We also conducted our research in the context of a specific sensemaking task between two peers. Future research is warranted that explores our design considerations in other collaborative contexts, like larger groups, groups with a hierarchical structure of roles, or where privacy is a concern.

## 8 ACKNOWLEDGEMENTS

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