Shared Document Control in Multi-Device Classrooms

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ABSTRACT
Classrooms increasingly consist of multiple interactive surfaces and people bringing their own devices. Although generative and evaluative kinds of groupwork are common in college classrooms, the prevalent technology remains remote-controlled polling systems. Equally relevant, but less explored are CSCW systems for these multi-device ecologies that facilitate ad-hoc groupwork around several documents. We report on a detailed naturalistic use of groupware in classrooms, where document control was shared equally among meeting participants and multiple entry points were available. Participants used SAGE2 in two classrooms over an eight-week period. With SAGE2, people may use different devices to share and control shared documents simultaneously. We examine how shared document control was treated and managed by participants in medium-sized meetings (8–16 people) within a college classroom setting. Findings reveal that the orderly structures of conversational turn-taking and bodily conduct organized turn-taking in shared document control.

Author Keywords
Shared control; multi-device ecosystems; document-centric collaboration; collocated interaction.

ACM Classification Keywords
H.5.3. Group and Organization Interfaces: Computer-supported cooperative work.

INTRODUCTION
Classrooms are continually evolving as multi-device ecosystems with multiple interactive surfaces [3] and people bringing their own devices [4]. However, the prevalent technology in college classrooms continues to be classroom response systems (CRS) and traditional slideware. CRS are remote-controlled polling systems used for answering multiple-choice questions. Slides are used to deliver one-to-many informative presentations. But technologies addressing the collaboration needs of ad-hoc groupwork in classrooms are yet to be adopted and still a nascent research. Particularly, varied device affordances and on-demand connectivity make college classrooms ripe for fostering rich collaborative technologies.

A major point of contention in designing groupware is how to achieve floor control [6]—prescribe technological means or rely on social methods? But recent CSCW and CSCL studies on multi-device classrooms primarily focus on understanding participants’ productivity, insights about collaboration—such as participation strategies and quality of ideas, and students’ learning outcomes. Equally relevant, but lacking is an understanding of how interaction design, like floor control processes, document access points, or control and deixis proxemics, facilitates and limits document-centric collaboration in multi-device ecologies.

Classrooms are institutional contexts involving certain divisions of labor, where collaboration is often informative—a one-to-many lecture. But for generative and evaluative kinds of groupwork, like brainstorming, design critique, or code review, richer forms of collaborative participation and ad-hoc interaction with documents becomes necessary. For instance, a teacher or student may share multiple documents on a public display to compare and connect, students and teachers may share and interact with shared content simultaneously to participate in a discourse, or a subset of group members may independently
review shared content to prepare for a later turn in talk. What design aspects facilitate document use during such collaborative participation is little explored, particularly in different types and differently sized meetings—which is crucial to gauge design scalability and versatility.

While seeming quite nontraditional, the classroom settings share many features typical of other workplace meetings where group members engage in presentation, discussion, critique, and co-creation. Supporting collocated groupwork in multi-device meetings has been a central concern in CSCW research for decades [11, 13, 14, 17, 37, 39]. Researchers have studied how small groups of experts collaborate around multiple surfaces [38], introduced group interaction techniques [25], developed purpose-designed applications [19], and proposed methodological frameworks to study collaboration [19, 39]. These studies examine how different devices afford different tasks and unpack consequences of the underpinning context of usage—for instance, examining which device was used for which task, or whether participants worked altogether or divided some tasks. Instead of activity analysis, our interest lies in specifically understanding how the interaction design of a groupware supports or hinders informal collaboration around documents. Precisely, we study implications of shared document control and multiple entry points to shared documents distributed across multiple devices.

This inquiry is significant because enabling multiple people to share and interact with shared documents is integral to the dynamics of collaboration [39]; interacting with shared documents enable publicly visible input such as gestures as oppose to private mouse clicks and key presses, providing intersubjectivity [35, 36, 39]; and multiple entry points facilitate fluid switching between tight and loosely coupled work [9]. Studying a naturalistic use of an already-adopted technology SAGE2 provided us an opportunity to explore how the system design accommodates context [16]. With SAGE2, multiple users may share content from different devices and control the publicly shared documents simultaneously; document control is shared equally among meeting participants. Since released in November 2014, SAGE2 has been adopted by 76 sites worldwide [32].

This paper contributes insights on how shared document control is treated and managed by participants in a medium-sized college classroom setting (8–16 people). Our group setting and size complements prior work on smaller groups, other types of meetings, and cross-sectional studies [1, 2]. Findings reveal that despite the meeting size, turn-taking in talk and bodily conduct organized turn-taking in shared document control to achieve in situ orderliness. We suggest designing shared document ownership to facilitate transitions between tight and loosely coupled work. In sum, we are concerned with identifying the problems and practicalities that pervade our attempts to enrich collocated multi-user interactions in multi-device ecosystems and provide support for ad-hoc interactions with documents.

BACKGROUND

Mechanics of collaboration have been extensively studied around documents [17], artifacts [37], single surfaces such as tabletops [35] and vertical displays [36], multiple surfaces [38], and more recently, in multi-device ecosystems [1, 19]. For decades, much of this work has focused on enabling efficient remote collaboration, but more recently, interest is growing in understanding how collaboration and communication strategies unfold in collocated settings due to the prevalence of multi-device ecosystems [8].

Typically, multi-device ecosystems constitute of one or more shared displays (multi-touch tabletops, [3]; wall displays, [36]; tables and walls, [38]) and people bringing their own devices and artifacts, such as handhelds, wearsables, laptops, or paper notebooks (BYOD, [4]). Interest in designing CSCW systems for these settings is not new. Take, for example, the Pebbles project connecting multiple PDAs to a single computer [24] or NASA’s MERBoard [30] allowing people to display documents from their personal computers via VNC (virtual network computing) during the early 2000s. In the subsequent years, technology has matured, and new device affordances have come into play. But few tools have emerged to support collocated groupwork in multi-device ecosystems. Much of the recent work focusses on designing specific cross-device interactions techniques (e.g., [25, 34]) or gaining insights about different tasks in collaboration (e.g., [3]). Prototype groupware systems that are developed in this research context are almost always purpose-built for experiments, for example, to study education [3], visualization [18], design learning [19], or slide presentations [1]. Note that tools for tabletops (e.g., the operating system of Microsoft’s PixelSense) or interactive whiteboards (e.g., SMART Board software) do not qualify as they are designed for multi-user interactions on single surfaces, not multi-device ecologies.

The most pertinent groupware to consider here is the recently introduced Microsoft’s Surface Hub, purposely designed to support workplace meetings, collocated and remote groupwork [22]. This single-computer backed interactive display supports multi-user interactions on the surface hub screen via pens, multi-touch, and wireless keyboards. But mobility of documents is only available via: (1) sending a link to share the surface hub screen with another meeting participant, (2) mirroring a personal device screen to surface hub screen via Miracast [23] or cables, (3) emailing a document, (4) saving it to OneDrive, or (5) sharing on Skype [22]. By lacking support for multiple people to quickly share and juxtapose multiple artifacts on the public display, such technologies are still limited in facilitating ad-hoc activities with and around documents.

To our interest is data-intensive groupwork. Collaborations are becoming data-intensive by the day, either in terms of the resolution of a single document or the number of documents involved. The popularity of large displays in
data-intensive collaboration owes largely to studies documenting increased productivity benefits, for instance, by comparing multiple documents [38] or quickly navigating high-resolution images [29].

SAGE2 (scalable amplified group environment) allows multiple people to share and juxtapose multiple artifacts on the public display (documents or device screens). It is cross-platform and scalable to support rendering of ultra-high-resolution images. SAGE2 research has examined data synchronization and visualization techniques leveraging the software architecture [5, 18]; however, we have little detailed understanding of how the design of SAGE2 supports the moment by moment involvement of talk, bodily conduct, and document-based interactions in these complex forms of collaboration.

For instance, how do group members organize turn-taking in controlling the public display? What issues do people face when moving from private to public workspaces and back? How do they manage referential activities? We investigate these in a classroom setting, using a video-based analysis. CSCW research to enhance classroom interactions have received continued interest since the 2000s. Much of this research has focused on standalone tabletops and interactive whiteboards (e.g., [21]). Only recently, researchers have started investigating the use of multi-device ecosystems, in K-12, college, and graduate classes, as well as design learning studios. But much of this research still reports on how the affordances of different surfaces are used for collaborative learning, such as brainstorming or designing a university course [3, 19]. For instance, studies report that availability of multiple inputs increase productivity and people could readily transition focus during shifting between various devices. What is then missing in the literature is an understanding of how the interaction design of a groupware—particularly, shared document control and multiple entry points across varied devices—supports/hinders informal collaboration around documents in a classroom setting.

We situate this study around the critical debate of whether to design a tool to democratize or constrain shared control, to strongly enforce turn taking or provide many unconstrained entry points. Constraints are crucial to collaboration but understanding how different degrees of constraints support smooth collaboration requires studying the design of a system in its naturalistic use [39]. Research on collocated interaction has just started exploring group awareness and importance of background information in multi-device ecosystems [3, 8, 19]. Our work contributes to this literature by studying shared document control in medium-sized classroom meetings, exploring whether social processes achieving orderliness in smaller meetings continue to do so, and identifying any subsequent conflicts and constraints. Although this paper focuses on the college classroom setting, our data can also inform groupware design for other types of multi-device ecosystems.

SAGE2
SAGE2 is a software framework, the second-generation scalable adaptive group environment (previously scalable adaptive graphics environment, SAGE, [28]). More than a decade ago, SAGE was developed to facilitate data-intensive collaboration around large, high-resolution displays, particularly to render various networked applications on a central display [27]. SAGE2 extends SAGE by supporting a wider variety of document types and various input modalities, such as touch and touchless interactions. SAGE2 is a web-based middleware that allows multiple users to view and share documents across multiple devices without requiring any installation other than having an up-to-date browser. Besides scalable resolution, SAGE2 offers window management, pixel streaming, and heterogeneous multi-user event handling. It is designed to support groupwork by providing a shared interface to collaborators. The shared interface, typically a large public display, is either driven by a single computer or a cluster. The driving machine runs the SAGE2 server and hosts several web pages, such as the SAGE UI page. SAGE UI is the primary user interface for SAGE2 (Figure 2a). To launch the SAGE UI, users need to visit a URL using any browser on their personal device. A password is required to access a SAGE2 meeting. After the password is provided, users choose a custom color and label for the SAGE2 pointer. SAGE2 pointer allows users to interact with files on the public display, such as to maximize a window, play a video, or close an application. Multiple users can interact with artifacts on the shared display concurrently. No explicit permission system is provided, and group coordination is left to ordinary social protocols. When an individual chooses to use the SAGE2 pointer, the local pointer on the personal device is locked, with move and click events sent to the web server to control the public SAGE2 pointer (Figure 2c). On users’ personal device, SAGE UI provides a graphical representation of the public display (Figure 2b) and window management actions, such as moving, resizing, and closing a shared window. Apart from sharing documents and applications, users may also choose to publicly share their computer screen via a live video stream (desktop pushing). It is the primary groupware used in two meeting rooms at the Electronic Visualization Laboratory: Cyber-Commons and CAVE2 (Figure 1).

STUDY SETTING AND METHODS
Setting
The Cyber-Commons is a 24 ft. wide x 42 ft. long (7.3 m x 12.8 m) room with a 21 ft. wide x 6 ft. tall (6.4 m x 1.8 m) tiled display at the front (Figure 1, left). The large display is a 17-megapixel LCD screen with a touch screen overlay and used for groupwork during meetings as well as classroom lectures. The room consists of movable tables and chairs and seats about 40 people. The CAVE2 is a physically smaller meeting space, a 22 ft. (6.7 m) diameter cylinder, with much more screen real-estate than Cyber-Commons, an ideal space for seminar-type classes.
small group meetings (Figure 1, right). Note that classrooms exactly like Cyber-Commons and CAVE2 may remain exotic in the near future; but large, high-resolution tiled displays, flat or curved, are now more prevalent than ever. While the groupwork discussed in this paper is influenced by the specifics of these two classrooms, the focus on individual’s talk and bodily conduct, and the issues in document-based interactions with SAGE2 (hereafter SAGE UI) transcend the classroom hardware and could be applied to other multi-device ecosystems.

Like a doctor’s office or courtroom, classrooms are institutional contexts, which means classroom settings involve certain divisions of labor, allocation of responsibilities, and different types of expertise or norms. Instructor and student roles bring along certain norms that are partially enacted through prescribed rules around who should speak when [20]. However, talk and bodily conduct cannot be completely prescribed [10], and orderliness within an institutionality is still achieved moment-to-moment. Here, we follow the longstanding tradition of video-based analysis in CSCW research to understand technology in use. Video recordings have been extensively used to study document interaction and work practices [11, 17]. Rather than a statistical breakdown of use cases, video forces attention on the moment-by-moment production of technologically mediated action, and in the past, has illuminated interaction facets overlooked by other methods.

Our study considered two classes offered by Dana (female, 46), a Professor in the School of Design, in Spring 2017: a project practicum course (hereafter, DE 4000) and a design elective course (hereafter, DE 4200). Both courses were 15-week long, met once a week, and constituted of a consecutive lecture and lab session—each session lasting for 2 hours and 40 minutes. Both these courses were offered at least once before. Dana has been teaching classes using SAGE UI in Cyber-Commons since 2015. Seven upper-level undergraduate (senior) students enrolled in DE 4000 and 12 graduate students in DE 4200. DE 4000 met in the CAVE2 room and DE 4200 in the Cyber-Commons (see Figure 1). All students were design majors except one Computer Science graduate student in DE 4000. DE 4200 was co-taught by an adjunct instructor, Tom (male, 57). For DE 4200, students were tasked with designing a tablet application (each project group was loaned a tablet, which was brought to the class meetings), while for DE 4000, students engaged in multiple projects, one of which was to design an art installation concept for a public arts venue, a 3,000+ square foot LED screen. These classes were chosen as they frequently required groupwork such as project brainstorming, design review, and design critique.

Methods
Our study was undertaken during the last eight weeks of the course as early class meetings were used to visit client sites and provide introductory lectures on SAGE2 to familiarize students. We chose to capture the emerging work practices after group members were sufficiently exposed to the environment (displays); with fewer chances of encountering novelty effects. For these eight weeks, class meetings were
used for groupwork, lectures, presentations, discussions, site visits, and project reviews. During these meetings, group members used personal laptops and tablets alongside large displays to view and share multiple documents. This study was approved by an IRB. Group interactions in the two classrooms were captured using two room cameras (front and back). No researchers were present during these video recordings. In sum, we collected a corpus of video recordings totaling about 48 hours, involving 20 regular participants across 12 sessions. The video data were used to conduct a detailed interaction analysis. We focus on the interactional location and the features of talk and bodily conduct around document-based interactions [11, 12, 17]—particularly shared document control.

Our approach is phenomenologically grounded, and draws from the enactment perspective, framing what users do with technology, not as an appropriation of existing structures embedded within technology, but emergent structures shaping the situated use of technology [16]. With the goal to better understand the details of particular situations of document use, one researcher watched all 48 hours of video and flagged clips of shared document control. The resulting 44 clips were then examined in group data sessions to understand how the design of SAGE UI supported ad-hoc interactions with documents. Next, we present detailed examples of participants’ interactional practices, focusing on how shared document control is treated and managed in collocated groupwork.

**FINDINGS**

In this section, we present several fragments and narrate occurrences that feature different aspects of shared document control. In the first set of fragments, we see how turn allocation is organized between students and between student and teacher. Second, we show how shared control facilitated distribution of responsibilities during groupwork. Third, we look at how people use shared control to prepare for their upcoming turn in talk. Lastly, we consider how multiple entry points to shared documents may create conflict in perceptual proxemics. Each of the fragments reveals how individuals treat and manage shared document control during different tasks, from project presentation, design critique, to project brainstorming. These fragments include occurrences from both the Cyber-commons and CAVE2 classroom (see Figure 1).

**Turn-Taking in Shared Control**

In the first fragment (DE 4000 in CAVE2), Dana has just found out that her students had trouble with a coding assignment. She decides to teach them by doing a part of the assignment in class (Figure 3A). She shares the course website and an IDE (integrated development editor) on the public display. She then starts working on the IDE on her laptop while demonstrating parts of the assignment to her class. Another student, P, joins in late. Dana leans in toward P’s laptop and asks if he was able to do the assignment (Figure 3B). P mentions that he has successfully completed the assignment. Dana stops her demonstration and asks P to...
share his work with the class. She explicitly allocates turn in control to a student, using talk and bodily conduct. P shares his project alongside Dana’s shared content, rearranges both, and continues working on his IDE. Meanwhile, Dana instructs other students in the class (Figure 3C). After a while, Dana orients toward P and says, “P you want to show us” (Figure 3D). Dana orients her body toward the part of the display where P’s document resides, uses a deictic gesture, and tells the class “Ok (.) guys (.) you can see P’s project.” P stats demonstrating his project, interacting with the shared document while talking. After showing the visual model of the project, we see Dana and P discussing an aspect of the assignment. While explaining to Dana, P asks whether to show the code. Dana gives explicit permission, and P continues.

Several things are of importance here. First, we see the explicit permission request and granting between a student and teacher to organize turn-taking in shared control. Second, turn-taking in control did not imply turn-taking in talk; P shared content and was interacting with the documents, but did not take the floor to talk. Third, floor control was allocated explicitly by the teacher by bringing the class’s attention to the shared document and enforcing P as the current speaker. Finally, we see a need to share a new document arising out of talk (the script of the visual model). This is treated by the student as a transition-relevance place in document control. P explicitly asks for permission before self-selecting turn in document control. This fragment reveals an explicit verbal exchange of permissions between meeting participants and an explicit verbal declaration of floor ownership.

The next fragment shows how students organized shared document control during a design review session (Figure 4).

Here, the class is having a design review with external clients middle of the term. The clients, instructors and teaching assistants are situated in the two rows near the large display. Alice and her group have just finished presenting their project and retreating to their seats (Figure 4). Dana looks to the class and nods to the next group indicating their turn in presenting. The three students stand up and wait on E. E, one of the group members has the SAGE UI open on her laptop. While standing near her seat, she informs Alice, one of the preceding group members, that she is self-selecting her turn to control the public display (“so, I will”). Alice provides an affirmation as she settles down. E deletes the documents currently shared on the public display, then uploads her project document and walks up to the display together with the two other students. Throughout the presentation, E stands near the display, holds her laptop as a handheld, and controls the shared document (Figure 5).

This fragment revealed how students explicitly took over control of the public display during an informal design review presentation. Note that multiple documents were shared and juxtaposed during each presentation. Here, as one group of students began to retreat from the display to their respective seats, that bodily conduct was treated as a transition-relevance place in shared control, along with the teacher’s nod. Interestingly, we also saw how documents were shared as a preparation for the upcoming talk. Meaning, the next group of students started setting the stage using shared document control before they took their position in front of the class or the stage. We did not find shared document control and multiple entry points hampering order in collocated groupwork.

**Distribution of Responsibilities**

We observed shared document control being implicitly used to distribute responsibilities. In one instance, a student had opened four documents in the CAVE2 classroom and is talking about his project. Dana is looking at the large display, laid back in her chair. Sometime within the talk, Dana leans into her laptop, opens the SAGE UI and slowly organizes the documents on the display, also resizing them for a better shared sensemaking. We find her rearranging documents on the public display several times while another group member is talking—during design reviews or presentations. However, when any student self-selected a turn in controlling a document shared by another student, it
was either structured by talk (e.g., Figure 4) or organized by bodily conduct (e.g., moving away from the display or releasing the floor for turn-taking in talk). One exception to this norm was during team presentations, where 3-4 students together shared content on the public display. We observed one of the team members sharing responsibilities, like resizing or rearranging another team member’s shared document or sharing new relevant content, while she/he is engaged in talk, without implicit or explicit permission.

**Marshalling Resources**

In a previous fragment (Figure 4), we show how meeting participants, preparing to take floor, leverage the shared control of SAGE UI. They started to share documents on the public display and removed previously shared content while they waited for the previous presentation team to retreat and move to the front of the display.

Consider another instance. All students were asked to give a quick update on their projects (1 minute) at the end of a student research talk. While the talk neared its end, others started sharing their update document. It was interesting because the shared documents were barely visible, thus, not obstructing the ongoing presentation content. Those documents were anchored at the display borders (Figure 6). Once the presentation ended, students quickly dragged their shared content to the middle of the display and presented their update. The order of the update presentation followed the physical arrangement of the class—counter-clockwise from front-left of the display, not the spatial position of the shared documents on the display. Here, we find participants using shared document control and multiple entry points (any personal device with a web browser) to marshal resources for their turn in talk. Note the anchoring of shared documents before a turn in talk was not a system feature, rather a situated use of the technology.

**Conflicts and Constraints**

In the following fragment, we find different device affordances taking precedence over an appropriation of existing system functionalities, in turn creating conflicts and constraints for ad-hoc groupwork. By unpacking these consequences, we try to identify the interaction patterns emerging from the situated use of the technology that may inform future design decisions.

In this fragment (DE 4200 taking place in Cyber-Commons), two visitors (external clients) have been invited to conduct design review of student projects (Figure 7). Student teams have been taking turns in presenting their projects. We look at one of these team presentations. Multiple project documents are juxtaposed on the large display; a student E and visitor 1 are talking about an application screen while both are looking at a tablet lying on the table in front of the visitors. SAGE UI is open on E’s laptop and situated on the same table nearby E. E’s two teammates, two instructors, a teaching assistant, and two visitors are oriented toward the tablet. To answer a question raised by visitor 1, E says, “It looks different (.)”, then orients herself toward the public display, says “from”, and points in mid-air to a document. The document she is referring here has multiple screenshots of a tablet screen. E walks up near the large display to point to one of those screenshots. Pointing on the display, she says, “this little guy was the original landing page”. E continues to talk, referring to the image, but orienting toward visitor 1 (“where you would see”). Visitor 1 stands up and walks up to the display. For the next minute, they talk around that image standing in front of the document and then return to their original positions (Figure 7).

Here, two devices are in play, a personal laptop and a public large display. Access to reorganize or resize shared document is available via the laptop. But, we find the meeting participant choosing to physically navigate near the far-end of the display, thereby situating herself physically closer to the document referenced in talk. In this fragment, fine-grained deixis was achieved by physical navigation, not system features like using the SAGE2 pointer (Figure 2C). By walking up to the display, E’s bodily conduct is made broadly visible, and being treated as a turn-holding cue in talk [31, 33]. Also note that the user in this fragment has already assumed the stage (i.e., situated in front of the
display) before physically referencing documents in talk. This is important to consider because large display interaction techniques for accessing out-of-reach content—without physical navigation—has been researched for decades; new interaction techniques draw from multiple interaction modalities to design solutions for deixis proxemics [26]. This fragment shows how bodily conduct in deictic pointing may facilitate talk in groupwork.

Second, although the participant’s bodily conduct managed floor control processes, we find it creating a conflict in perceptual proxemics for other group members. First, to follow along E’s talk, visitor 1 needed to move near the display. She was far away to examine sufficient detail in the image and participate in a tightly-coupled collaborative discourse with E. This was successfully achieved. But, when the two group members started talking near the large display, they created an o-space formation near it, which left those far from the display on the outside of the ring, not a part of the interaction [15]. As a result, there appears no way for other group members to engage in the ongoing talk; neither for those who were tightly coupled in the discussion preceding the o-space formation (we see them oriented toward the L-shaped f-formation) nor for the loosely-coupled rest of the class who may be following the discussion passively. The design of SAGE UI did not allow independent review of shared documents, meaning any interaction with the shared content on personal devices, such as zooming in a document, although permissible, is immediately rendered on the public display: Thus, shared document control seem to constrain groupwork here.

Later in the same fragment, we see another instance of ad-hoc document sharing during design review. To respond to a visitor’s question, E props her laptop by the edge of the table and pulls up a document on the public display via screen sharing. As she talks, oriented toward the visitor and exchanging glances between her and the laptop screen, she scrolls the document on her laptop using the local pointer (Figure 8a). The easily accessible document entry-point and shared control facilitated document sharing and intersubjectivity. The document interaction itself (scrolling up and down) was further treated as a referent within E’s ongoing talk (“this”). However, note that this was a coarse-grained referencing.

Also, important in this fragment is the use of laptop as a handheld, similar to the instance in Figure 5. We found participants working around the constraints of device affordances to avail entry points to shared document control. Being a web page, SAGE UI can also be launched from any handheld device (Figure 8b). However, the interface does not appear to be adapted for mobile use. We did not find participants using handhelds as entry points to control shared documents in our study.

Figure 8. During a group discussion, a student is using the SAGE UI and referencing to a document shared on the public display (A). SAGE UI launched on a mobile phone (B). Broadly speaking, SAGE UI is to any multi-device ecosystem as Windows Explorer is to a Windows computer; because SAGE UI is browser-based, devices only need to be connected to the web without any platform-specific constraints. Our findings show different aspects of how interaction with documents came to be organized drawing on the nature of task at hand. The fragments we presented here only encompass the use of multiple laptops and a large
processes instead of well-defined technological protocols affordances cases. The longitudinal study was carried on with as little longitudinally over eight weeks to identify emerging use findings. The system in use was already adopted by the community we studied. The system use was studied emphasize here the ecological and external validity of these findings. The system in use was already adopted by the community we studied. The system use was studied longitudinally over eight weeks to identify emerging use cases. The longitudinal study was carried on with as little research intervention as possible. Settings, class curriculum, participants, devices, or use of the devices were all authentic. The average meeting size was 10. Except one, participants were not computer science students. No researcher or developer of the SAGE2 project was present during the meetings.

Second, we identify two interaction design concepts that arbitrated the treatment of shared document control during groupwork: shared document ownership and device affordances.

**Managing Shared Document Control**

Issues of document control in groupwork has been studied extensively, in single display groupware, such as multi-touch tabletops or a large shared display with multiple mice/pens (e.g., [14, 24, 35, 36]). Some studies have argued that if interfaces are more inviting and easier to use for group members whenever they want to interact, it could be less obvious how a collocated group should coordinate their interactions, leading to anger, frustration, and disengagement [39]. Contrary to that, our findings revealed people using talk and bodily conduct to manage turn allocation in controlling documents on a shared display in a multi-device classroom; orderliness was achieved via social processes. However, note that arguments for a strict technological protocol for turn-taking in document-centric interactions stem from studies on single multitouch tabletops, not multi-device ecologies with large public displays and personal devices. Broadly then, we argue that the loci of document control, the availability, and placement of entry points, should be easily accessible during a collaborative discourse—to facilitate common turn taking strategies, such as self-selecting the floor, repairing a turn, or holding the floor. As we saw in our results, turn taking in shared control is interwoven with turn taking in talk (Figures 3 and 8). Permission to control the shared display was provided via implicit bodily conduct (e.g., teacher’s nod, Figure 4, or reaching the end of a talk, Figure 6), explicit talk (e.g., “Yeah, go ahead, put it up there”, Figure 3) or implicit talk (e.g., “P, you want to show us through”, Figure 3). Interestingly, permission exchanges between teacher and students were always explicit (e.g., “Do you want me this to share with you”, Figure 3), among students, permissions ranged from implicit (Figure 6) to explicit (Figure 4). Sometimes, multiple permission systems were at play. For instance, in Figure 4, permission to take turn in control was conveyed implicitly by the teacher (bodily conduct) and explicitly by another student (Alice).

Multiple entry points to control the public display, to share content and then interact with the shared content, did not only help meeting participants to quickly bring up documents in a collaborative discourse (e.g., Figures 3C and 8) but also to prepare for turn-taking in talk. The fragments in Figures 4 and 6 show how participants prepared for an immediate and later turn in talk, respectively. For an immediate turn in talk, we find a meeting participant putting documents on the public display from personal devices while walking to the stage (Figure 4). For a later turn in talk, participants shared documents on the public display well before their turn, but deliberately anchored them by the border of the display, with only a part of the document peeking out, enough to quickly bring it to the middle of the display and maximize during their turn in talk (Figure 6). Finally, when necessary, group members implicitly assumed responsibilities to organize shared documents during another’s turn in talk, not as a sign to interrupt, but as a distribution of document control duties (see Section Distribution of Responsibilities). Thus, shared document control enabled groups to distribute document driving responsibilities. Finally, in terms of affordances, the multi-device ecosystem provided several entry points, with the loci of control conveniently available at people’s personal devices.

**Shared Document Ownership**

A major constraint arising out of the design of shared document control in SAGE UI was that participants could not review shared documents independently. Any interaction with the shared documents in the SAGE UI was immediately reflected on the public display. This significantly deterred loosely-coupled work, where one or a subset of users review and reflect on shared content, not
actively engaging with other group members. For instance, in Figure 7, when a pair of users engaged in a tightly coupled discussion in front of the large display, that document became unavailable to other group members—despite having an entry point to the document right on their personal devices, independent interactions, like zooming in or navigating the document, without disrupting the ongoing discussion was not possible. Thus, the shared document was bounded up in an activity and rendered inaccessible.

Collocated groupwork ranges from loosely coupled, like passively listening to a presentation, to tightly coupled, like working on a design sketch together. Collaborative coupling depends on the extent of coordination, synchrony, and action dependency. While some group members are tightly coupled, others may be conducting independent tasks and only loosely coupled [1, 9]. Often tightly coupled work stem from moments of reflective loosely coupled work (and vice versa); thus, systems offering shared document control need to facilitate an easy transition between loose and tightly coupled activities.

SAGE UI provides a graphical representation of the shared artifacts on personal devices but does not support independent document navigation or annotation (see Figure 2b). The shared documents cannot be temporarily owned by meeting participants, so as to allow an individual to navigate and annotate a shared document independent of other group members. To address this constraint, another open system, Office Social, decouples shared document control from shared document ownership [1]. By just toggling a button, one can switch between the Review and Interaction Mode of Office Social. With Review Mode, document interactions are independent and not rendered on the public display; to make their document interactions public, one would switch to the Interaction Mode. However, Office Social only dealt with a single slide deck, compared with varied documents and display resolutions supported by SAGE2, which makes designing shared document ownership for SAGE2 nontrivial. Note that users may not always want to permanently save a document for future use (or be allowed), but transiently share ownership. One way of doing this might be providing a UI mode switch option between ‘review’ and ‘live’, where an artifact could be made live post-review—either reflecting or discarding the changes done independently; or taking a snapshot of a document view like proposed in MeetAlive [7].

Device Affordances
Finally, the advantage of a multi-device ecosystem is how different devices complement their affordances. For instance, tabletops are good for small-scale tightly-coupled collaboration, large displays afford parallel task, rendering high-resolution images, and intersubjectivity for large groups; handhelds are good remote controllers, like being used as PowerPoint clicker (Office Remote), tablets suit as controllers for collaborative visualization. When designing CSCW systems for multi-device ecologies and offering shared document control to facilitate ad-hoc groupwork, it is essential to draw on the diverse affordances of the participating devices. Although the SAGE UI was available from different devices as an entry point to document sharing and control, it was not used beyond desktops. Probably, because the system design only optimized the interface layout to device sizes but did not consider affordances (Figures 5 and 8). For instance, drawing on their mobility, handheld and wearable UI may be designed to support annotation, document navigation (next and previous), and fine-grained deictic pointing from afar. Research on cross-device interactions has introduced promising benchmark techniques for an individual to draw on complementary device affordances and accomplish a task [25, 34]. This could be taken further and allow multiple users to draw on an ensemble of personal devices and create new input methods for shared interactions. How would collocated groupwork practices shape the situated use of such technologies remains to be explored.

CONCLUSION
This paper explored equally shared document control with multiple entry points in a multi-device classroom. By studying a naturalistic use of SAGE2, a collaborative technology that supports collocated groupwork in multi-device ecosystems, for eight weeks in two classrooms, we examined how shared document control is organized and when conflicts and constraints arise. Findings reveal that orderly structures of conversational turn-taking and bodily conduct organized turn-taking in shared document control in a medium-sized college classroom setting (8–16 people). Our group setting and size complements prior work on smaller groups and other multi-device meeting types. We show that permissions to control the shared display were exchanged implicitly within students and explicitly between student and teacher; participants used shared document control to prepare for their turn in talk; and the lack of shared ownership of documents constrained loosely coupled work, such as independent review and reflection.

SAGE2, the scalable amplified group environment, is widely used in real work settings to meet the needs of data-intensive collaboration. By considering how the SAGE2 system fractures and fragments everyday interactions in the device ecosystem, we can make sense of how participants accommodate their work practices and highlight design issues to consider in future. This suggests further detailed studies of collocated interactions are needed to understand nuanced socio-technical challenges as we move toward richer multi-device and multi-artifact ecosystems.

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