Challenges and Opportunities for Multi-Device Management in Classrooms

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Orchestrating digital devices in classrooms is challenging. We conducted an observational study to understand how teachers manage multi-device classrooms involving tablets, computers, and video-projectors. Two categories of device management tasks stand out: content sharing and remote control. Based on our observations, we identify 17 multi-device management tasks that are important to teachers in this specific device configuration. We conducted a second study to investigate how teachers could perform these tasks with the help of a smartwatch. For remote control tasks, participants preferred smartwatches to interact from a distance, whereas for content sharing tasks they preferred to interact directly with the devices displaying the content. We outline design opportunities for multi-device management controls in learning environments, and challenges for HCI research on classroom orchestration.

CCS Concepts: • **Human-centered computing → Interaction design process and methods**; **Empirical studies in interaction design**; *Interaction techniques*; • **Applied computing → Education**.

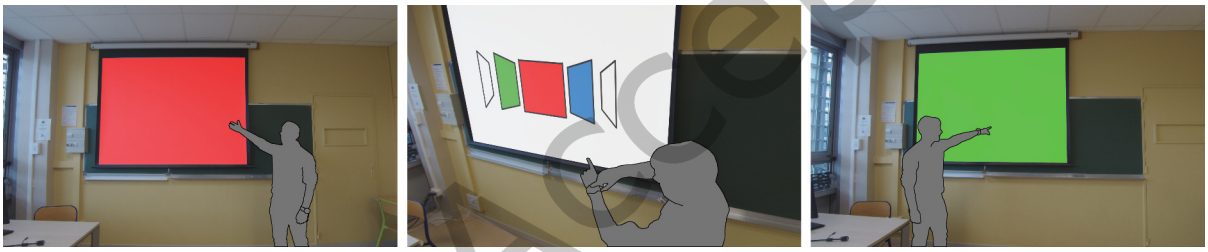

Fig. 1. A teacher enacting an application switching task on a projector using a smartwatch.

1 INTRODUCTION

From primary schools to universities, digital tools are now widely used in classrooms [53]. Teachers have to manage complex ecosystems of devices ranging from personal computers to tablets, smartphones, and video-projectors, not to mention whiteboards, notebooks, and paper sheets. These devices can be used in a number of configurations that evolve over the course of a learning activity.

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For teachers, the management of such device ecosystems is particularly challenging. In practice, this can become a barrier to the use of digital tools in classrooms [26]. Indeed, when breakdowns occur, teachers and learners can drift away from their main activity, as recovering from errors is costly in time and distraction [48], and they may not want to renew such experiences.

The concept of classroom orchestration can help us frame questions of planning and managing digital tools in classrooms in real-time [16]. Orchestration proposes models of pedagogical activities, while acknowledging their need to be adapted to local constraints. Most orchestration technology has focused on managing pedagogical activities [10, 13] which, while important, often ignores the challenges related to multi-device management in ecological settings. In this paper, we focus precisely on how teachers manage such practicalities. To understand how to better design orchestrable technologies, we conducted two studies tackling the following questions:

RQ1 *What are the main device management tasks in classrooms?* We conducted an observational study of four mathematics teachers in nine different classes. The objective of this study was to identify how teachers manage their digital class and the challenges they face. We used this study to define 17 device management tasks that teachers consider relevant.

RQ2 *What are meaningful interaction strategies for managing multi-device classrooms?* We conducted a second study, inspired by elicitation methods, to understand the strategies teachers would use to perform the 17 device management tasks. Given the existing limitations of tablets and smartphones, we introduced a smartwatch as a generic controller for device management tasks.

The results of our observational study offer a better understanding of the different constraints that teachers have to face when managing a heterogeneous ecosystem of devices in classrooms. We identify five categories of multi-device management for orchestration goals and two major issues for device management in classrooms, i.e., supporting content sharing and remote control tasks.

In our second study, we identify seven major interaction strategies to perform content sharing and remote control tasks in classrooms. Teachers prefer using a smartwatch to control remote devices, proposing simple strategies and replicating known gestures. They also frequently used their device for authentication purposes. For content sharing tasks, teachers prefer more complex gesture sequences, which rely more heavily on tablets and involve more implicit actions. Moreover, the strategies vary depending on the content to be shared (an element vs. the whole application). Finally, we derive design opportunities related to remote control tasks, lightweight authentication, and collaborative gestures and outline two challenges for future research on device management in classrooms related to implicit interaction and distributed interaction metaphors.

2 RELATED WORK

2.1 Orchestration in CSCL

It is particularly challenging to anticipate how learning activities will unfold. The introduction of digital tools adds another layer of complexity [48] as well as a new source of breakdowns [26]. Teachers have to manage their activities but also devices involved in classroom activities, often in a dynamic manner, under time constraints, with numerous learners, and pedagogical goals. Although it can be prepared, the unexpected often happens and live adjustments are needed.

Orchestration provides useful concepts for framing the challenges teachers face when managing classroom activities, from planning to real-time management of activities, in a multi-constraint context [10, 16]. It initially focused on facilitating how teachers drive learning activities by proposing principles to structure and conduct activities [10]. However, the question of orchestrability [11], i.e., how digital tools can be orchestrated has become central to research on orchestration [41, 45]. This involves paying attention to individuals, groups, and classrooms [13]. Yet even if these criteria are met, teachers need to adapt their plans to emerging constraints, and adapt tools to their local needs. Indeed, a constant challenge of orchestration lies in the messiness of learning

activities. Whether it is to deal with time constraints and changes in a suitable manner (e.g. adding a few minutes to an activity) [15], to gracefully handle changes in collaborative structures (e.g. switch from individual to group work) [40].

If technical approaches supporting better planning [18], alleviating teachers' cognitive load with mixed initiative systems [21] or with situated visualization [20] are promising. Some very basic interaction challenges remain: managing devices, the content they display, the activities they support are not simple usability issues. Teachers need the ability to control multi-device classrooms in a seamless manner, recover from technical breakdowns, and dynamically manage content.

2.2 Managing devices in classrooms

Device management tasks can vary greatly depending on orchestration goals. When it comes to controlling the flow and resources of the activity, few Learning Management Systems (LMS) or Orchestration Systems offer the flexibility of paper-based activities. Whereas paper can be distributed and collected easily, handed out seamlessly from one person to another, or reassembled at will, digital tools rarely offer the same level of control. LMS are often cumbersome when teachers want to adjust learners' activities to situational constraints. Shared folders/drives form an alternative widely used in classrooms[1], but these offer few dynamic sharing mechanisms. Sharples [48] and Looi [32] have already pointed out the risks of orchestration technology adding more complexity than simplification in activity management.

This paper focuses on how orchestration tools could better support cross device interaction. We build upon Tchounikine's call for orchestrable technologies [50], and argue that designers should consider how systems can better fit teachers' practices and be adapted to local classroom constraints.

Brudy's *et al.* recent survey on cross-device interaction [7] identified 15 projects related to multi-device management in classrooms. Most focus on learners, whereas we are interested in teachers. Moreover, device configuration is rarely considered. These projects assume that no interaction is required to pair devices together and that devices are already inter-connected [5, 29, 34, 56]. Fine control over documents or other forms of content to share between devices is also something that is often overlooked, although this is a very common task for teachers. These assumptions may be problematic in digital classrooms that involve tablets, group work or dynamic reorganizations.

Previous work on orchestration in multi-device environments has shown that using devices such as computers or tablets obliges teachers to go back to their desk or reduce orchestration work [30]. In this context, mobile devices could act as universal remotes [2], enabling teachers to manage and control devices from anywhere. For instance, when it comes to managing attention and distractions, Apple Classroom lets teachers lock the screens or mute learners' tablets. In HCI, remote control has been particularly studied in the context of smartphones controlling media centers [2] or, more recently, smartwatches [22, 33].

Our work draws inspiration from the use of such mobile or wearable devices to control computers or tablets in classrooms. And it seeks to understand under which conditions and for which types of tasks, wearable devices could be used to facilitate multi-device management in classrooms for orchestration purposes.

3 STUDY 1: DEVICE MANAGEMENT IN CLASSROOMS

We conducted an observational study to identify *the main device management tasks of teachers in classrooms.* The focus was on how teachers manage physical and digital resources, what they do themselves, and what they ask learners to do, and the breakdowns they encountered throughout the class.

[1]In January 2019, Google claimed 40 million users for G Suite for Education https://www.bgr.in/news/google-classroom-program-now-has-40-million-users-30-million-chromebooks-learners-765359/

3.1 Classes observed

The video-recordings of nine public middle-school classes delivered by four teachers (2 male, 2 female) were analysed. The schools were located in neighbourhoods with varied social backgrounds in a large French metropolitan city. The classes were all on the same topic, double distribution, and delivered to 8th graders (13/14 years old). The classes all followed the same structure, divided into three steps (Fig. 2):

(1) Reminders of the previous class, and a lecture on double distribution on the whiteboard;
(2) Walkthrough of examples illustrating the topic of the lesson on the whiteboard, and
(3) Individual exercises on tablets.

The teachers used a tablet to control the exercise platform. The duration of the first two steps was not fixed, whereas the last step had to last 30 minutes for an overall class duration of 55 minutes. Table 1 summarizes the observations.

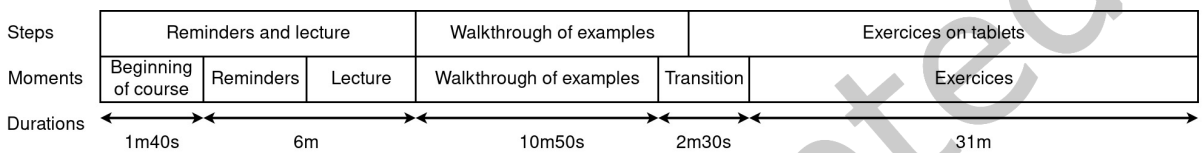

Fig. 2. Overview of the activity, and mean duration of each moment.

3.2 Class Set-up and Devices

The learners and teachers all used 10" Android tablets. Every teacher used a video-projector linked to a computer (a fixed PC in seven observations and a laptop in two observations). In eight observations (**O1** to **O8**), the video-projection was directly on the whiteboard, while in one observation (**O9**), a projection screen in front of a blackboard was used. The classes had different spatial set-ups: one with L-shaped "islands" (3 observations); U facing the whiteboard (1 observation); and rows of tables for two learners side by side facing the whiteboard (5 observations). These were classrooms teachers and learners regularly use, in their usual set-up.

Observation	1	2	3	4	5	6	7	8	9
Teacher	T1	T1	T1	T2	T2	T3	T3	T3	T4
Devices	• Tablets • PC • Projector • Whiteboard	• Tablets • PC • Projector • Whiteboard	• Tablets • Laptop • Projector • Whiteboard	• Tablets • PC • Projector • Whiteboard	• Tablets • PC • Projector • Whiteboard	• Tablets • PC • Projector • Whiteboard	• Tablets • PC • Projector • Whiteboard	• Tablets • PC • Projector • Whiteboard	• Tablets • Laptop • Projector • Blackboard

Table 1. Classes observed by teacher and devices used.

3.3 Data and Analysis Method

The observations took place within a broader project focusing on pedagogy and learners' motivation (not influencing the orchestration or device management of teachers and learners). We met with the teachers before the observations, and gathered authorizations regarding video-recording. Wide-angle cameras were used to record each class and positioned so that learners who did not agree to be recorded were off-screen. The focus of our analysis was on teachers' behavior while orchestrating the class, with a special focus on their use of devices. Learners were considered as a whole, without any coding of their individual behavior. No observer was present during the recordings to limit external influences.

A thematic analysis [6] was conducted. The coding scheme was devised by the main author in collaboration with three co-authors. Each co-author analyzed one full video-recording. We confronted our codes until an agreement was reached on their meaning, naming, and hierarchy. To complete the latent thematic coding, the main analyst also labeled each action with more semantic information: (1) a brief description of the action; (2) goals when performing the action; (3) current moment of the activity; (4) modality of action and target of action.

In order to assess the relative importance of our themes in the orchestration process, we counted the number of actions (**n**) observed for each theme. This quantitative reporting is strongly linked to the activity and aims at giving insights into the relative importance of different actions. It should not be considered representative of a broader set of activities.

3.4 Results

The analysis of 279 actions performed by teachers to orchestrate a multi-device classroom led to the following themes:

(1)	Pedagogical interventions	109/279 actions
(2)	Device and activity configuration	94/279 actions
(3)	Activity flow management	44/279 actions
(4)	Learners' attention management	32/279 actions
(5)	School/class life management	17/279 actions

The results below center on the first four themes, as the last one was marginal and involved specific administrative tasks that were not necessarily mediated by technology (e.g. performing call attendance). Text in bold indicates categories of actions identified.

3.4.1 Pedagogical interventions. These actions were mainly performed when teachers interacted with learners for pedagogical purposes (exercises (**n**=64), examples (**n**=19), lectures and reminders of previous lectures (**n**=26)). This is the theme with most actions, amounting to more than a third of all the actions observed. The theme has three categories: classwide explanations, individual help, and class guidance. Teachers built on a variety of interaction modalities to manage the pedagogical aspects of the activity depending on the actions they wanted to perform. There is a distinction between pedagogical interventions at **class** or **individual** level.

For classwide actions, teachers mostly provided explanations during lectures, and guidance during exercises. For **classwide explanations** during lectures, teachers positioned themselves close to the **whiteboard**. They interacted with projected content by pointing (**n**=36) or writing on the whiteboard (**n**=29). When offering **class guidance** on exercises, teachers frequently switched from one device to another, e.g. from a **learner tablet** to the **video-projection**, to explain a concept to the class *"Follow my gesture on the board to understand the correction"* (**T2**). When teachers conducted pedagogical interventions, **transferring content from one device to another was challenging**. Indeed, teachers found it complicated to reproduce with technologies their habits such as distributing sheets of paper with corrections to the whole class or asking a learner to write down their solution on the whiteboard. Thus, content was often transferred manually, e.g. re-writing learners' answers from a tablet to the device connected to the video-projector to share the corrections with the class or re-writing the content on the whiteboard manually.

We also observed how **interacting with projected content** required going back to the projector to reach for the mouse or keyboard connected to the computer projecting the content, for actions as simple as scrolling, switching between applications or preventing the computer/projector from "sleeping".

When teachers were not interacting with the whole class, they performed actions at **individual** level, focusing on helping specific learners. This involved manipulating learners' tablets or notebooks (**n**=19). For example,

when a network problem occurred, teachers had to enter the learner's tablet in administrator mode in order to configure the network connection.

3.4.2 Device and activity configuration. These actions relate to how teachers managed devices in the classroom. They occured mostly at the beginning of the class and during the transition between lecture and exercises (42% and 47%, respectively, of actions related to device management taking place at the beginning of the activity or during the transition phase). The theme has four categories of actions: solving technical problems, giving instructions about device use, preventing or mitigating possible breakdowns, and setting up the activity on devices.

In many instances (**n**=23 of 94), teachers directly interacted with the **learners' tablets** to solve technical problems. They also used their **own tablets** to do so, e.g. when resetting wi-fi connections for the whole class. Most breakdowns we identified related to infrastructure or software issues. For example, teachers had to help students connect to the system *"Make sure that it is your credentials that are used on the tablet, and not those of the previous class."* (**T1**).

It is important to point out that teachers left their tablet on their desk, and went back and forth from the class to their desk. Tablets were cumbersome to carry, and teachers could not easily stow them away when they started interacting with learners. It seems that the spatial configuration of classes had little impact on device management, and especially, on teachers' mobility in the classroom. Teachers all moved between their desk and the learners' desks, and they did not seem to be influenced by the spatial set-up of their classrooms.

3.4.3 Activity flow management. These actions relate to the way teachers control the progress of the activity and the time constraints at **individual group** and **class level**. Teachers mostly managed the activity flow during exercises and the transition from lecture to exercises. The theme has four categories: managing time, managing progress in the activity, providing guidance to learners and the class to help them during the activity, and controlling the activity for a subset of the class.

Teachers managed the activity flow mostly through oral instructions. They conveyed information about the expected progress, i.e. the current step of the activity, or asked learners to move to the next step of the activity. During exercises, activity flow was managed mainly by providing learners with oral information about the expected progress or instructions for the activity, e.g. telling learners they should be on a specific part of the exercises.

Teachers often had to **unlock** or **control remotely** the content displayed on the tablets, mostly during the transition and exercise phases. In the set-up we observed, teachers had to "activate" exercises for them to become available on the learners' tablets. In order to manage progress, teachers frequently had to poll the class to know the extent to which learners progressed, e.g. *"It's okay, you're on the exercise now?"* **T4**.

3.4.4 Attention management. These actions relate to the way teachers manage learners' attention. A majority of attention management actions occurred during exercises, the transition from lecture to exercises, and at the beginning of the class. These actions correspond to attention breakdowns that are mitigated by the teacher. The theme has three categories, with two involving the use of notebooks or tablets: (1) managing learners' attention within the learning activity, e.g. asking *"can you refocus on the exercises?"* **T3**, (2) managing several **devices** in parallel during the same part of the activity, and maintaining attention on the relevant media. Here, the simple presence of tablets on the learners' desk at the beginning of the class could lead to extra attention management, e.g. **T3** repeating *"No, we don't touch the tablets now"* or **T1** asking learners to *"focus [their] attention"*, and (3) managing the transition from one tool to another, either when switching from a lecture to a paper-based activity at the beginning of the class, or between paper-based media and digital devices, e.g. *"Can you leave the tablets and refocus"* **T3** or *"Open your notebook to chapter 7"* **T1**.

Attention management involved a considerable amount of encouragement and directions from teachers. In practice, having **the screen and the sound** of the devices on was a **source of distraction that required some mitigation**.

3.5 Open challenges

In this first study, we investigated how teachers manage devices in the context of their existing activities. We determined two broad challenges crosscutting the five themes identified: sharing content across devices and controlling remotely one or multiple devices.

3.5.1 Content sharing tasks. They relate to moving content across devices (tablets or projector). In the observations, these tasks were all initiated by a teacher who shared content with individual learners or the whole classroom. Teachers can either share the whole screen of an application or an element (e.g. an exercise). Content sharing tasks are challenging because they often involve *configuration* steps that interfere with teachers' flow and pedagogical goals, and are not or only partially supported by existing learning platforms.

When conducting pedagogical interventions, teachers only had partial control over projecting content on the whiteboard or sharing it with learners. Learners had even less control and could not directly share content with the whole class or with another person. These sharing actions were all limited to what was enabled by their operating system and the learning platforms used. In the follow-up study we focus more specifically on how teachers can push content to one or several devices, whether a video projector or learners' tablets.

Research prototypes with device management and orchestration features [14, 29, 32] offer limited support for task sharing. Proxywork [52] and Shared orchestration [32] support sharing specific elements such as learners' answers or the whole application but only from a computer. While Unipad [29] only supports sharing answers from learners' tablets via video-projection. In this respect, some commercial systems are more advanced within their own ecosystem. For example, Apple classroom[2] supports content sharing of the application from the learners' (one or all) tablets, teachers' tablet or via the video-projector.

In the broader HCI literature, screen casting or UI distribution have been explored from the underlying software architectures, such as VNC-like protocols pushing all the pixels of a display to another (e.g. [49]), to higher level strategies supporting the distribution of specific UI elements (e.g. [1]). Several challenges remain nonetheless open. One is defining the configurations of device ecosystems [24], i.e. what can device share, broadcast, or receive, from whom and under which conditions, this is likely to happen before any activity starts. Another is how to specify sharing instructions on the fly, i.e. what to share, to which device, and with which constraints. Proximity [46] and beaming [4] are two popular strategies in the literature. A general assumption is that applications will have to be designed for specific types of multi-device sharing and offer (explicit or implicit) commands supporting it.

Overall academic and commercial systems are not geared towards multi-device sharing in learning situations. For instance, sharing content directly with learners, something that is straightforward with paper, is complex and becomes increasingly difficult when groups are involved or when learners require individualized content.

3.5.2 Remote control tasks. These relate mostly to managing presentations, the activity flow, and learners' attention. In our observations, these tasks were performed when teachers wanted to control either the learners' devices (unlocking content for instance) or the video-projector (controlling projected content from anywhere in the classroom).

To manage learners' progress in the activity, teachers have to control the content of tablets at individual or class level. This means ensuring progress throughout the activity, as well as making sure that learners are not stuck for learning or technical reasons. Moreover, digital devices can be distracting, and teachers struggle to

[2] Apple Classroom: https://apps.apple.com/us/app/classroom/id1085319084

manage learners' attention. In this case, remote control could consist in turning the screen or the sound output on and off.

Apple Classroom is the widespread system enabling remote control of devices. It enables teachers to manage the devices of a learner, a group of learners or the whole class. It also enables teachers to take control of the sound and screen of devices, as well as the applications launched on a learner's tablet. Few academic systems support these actions. While both Unipad [29] and TinkerLamp [14] let teachers regulate activity progress, learners' tablets cannot be remotely controlled.

In the HCI literature there is little discussion on how one user or category of users could take control of someone else device or of a group of devices. Most use cases related to remote control tasks involve multiple people having the ability to interact on a shared display whether it is a projection, a wall, a tabletop, or a media center. The settings typically vary from meeting spaces, to classrooms or homes. In such situation the main interaction strategy is some form or remote pointing [25] through a proxy [4] or through beaming [39]. There is very little discussion on nuanced user roles and rights in device management. How one user or category of users can control the devices of someone else or of a group still raise interaction and feedback challenges.

4 MULTI-DEVICE MANAGEMENT TASKS FOR CLASSROOMS

Based on the observations and the related work, we propose to describe multi-device management and orchestration tasks in classrooms along five design dimensions. We derived a set of 17 representative tasks. These tasks are generic enough to apply across various schools and levels. We focused on tasks where the teacher is the main orchestrator. More collaborative situations among learners are left for future work.

4.1 Design dimensions for device management

From our observations, we identified different parameters that characterize the actions performed by the teachers. We grouped these parameters into a first set of design dimensions. We coded the actions that could be performed with the different systems presented in the related work in order to validate our dimensions and the associated parameters. This allowed us to refine and stabilize our design dimensions.

We build upon our study results, three research prototypes tested in classrooms [14, 29, 32] and a commercial system (Apple classroom). We left out considerations related to technical problems, which go beyond direct device management, such as those identified in related work: network problems [30], communication between devices [23], and orchestration challenges such as monitoring progress [44] or activity scripting [12].

We propose to use the following five dimensions to describe device management tasks:

1. Teachers' tasks category. This dimension is divided into the two challenges previously discussed: (1) Content sharing linked to pedagogical interventions. While sharing with the class is widely supported via video-projection, one-to-one sharing and teacher-to-group content sharing are still poorly supported. (2) Remote control corresponding to activity management tasks, attention management tasks or taking over a device from a distance. These tasks were difficult to perform or appeared to draw teachers away from their main objective. They led to breakdowns in the activity, and tasks that teachers could not conduct but that could have been useful.

2. Objects manipulated. Teachers manage the devices at different levels of granularity: at UI/content level (e.g. when a teacher controls a specific exercise), at application level (e.g. the learning management system used by teachers), and at device level (e.g. when a teacher shuts down the screen of a tablet). Shared orchestration [32] proposes sharing specific elements such as learners' answers but also the whole application from learners' computers. Unipad supports sharing answers (element level) from learners' tablets to shared video-projection. Apple Classroom supports content sharing only at application level but offers a wider variety of source and target devices.

3. Source devices and **4. Target devices**. Regardless of the tasks or objects manipulated, most management tasks involve two types of devices: a source and one (or multiple) target(s). For both categories, we distinguish between teachers' devices and learners' devices. For example, teachers can share the screen of their tablet, a learner's tablet, a set of tablets or the computer connected to the video-projector. The same devices can be targets for remote control tasks.

5. Target users describes people involved in teachers' tasks. Teachers can interact with a specific learner, a group or the whole class. We did not add a category for source users since we only consider tasks triggered by teachers.

4.2 Device management tasks

The observations from study 1 were used to identify relevant device management tasks for classrooms. We focused on teachers' tasks, either controlling individual devices or the whole class. As tasks related to groups were not frequent in study 1, group and collaborative device management were left for future work.

We started by defining a set of 20 tasks, considering either tasks we observed or tasks that would have been useful but could not be performed (e.g. carried out through instructions rather than direct interventions). Then, we abstracted some tasks in order to make them more generic. For example, "bring all learners to the same exercise", "highlight an element for all learners", and "unlock a step for all learners" were abstracted into a single task "take control of all the tablets". We also specified tasks that were too generic, e.g. we divided "perform actions [tasks] on the projector" into four tasks: two related to sharing content from learners' tablets to the video-projection, and two related to remotely controlling the video-projection.

We obtained 19 device management tasks.This set of tasks was then presented to a professional UX designer working full-time on classroom learning systems to get external expert feedback which led us to reducing the set to 17 tasks (see table 2). We split the tasks according to the two categories identified as broader challenges: content sharing and remote control tasks.

4.2.1 Content sharing. Content sharing tasks cover all the tasks related to moving content across devices (tablets or projector). Such sharing problems have already been studied in the field of cross device interaction, with techniques for projecting and sharing UI elements and applications with other devices (see [7]).

We focus on teacher-centric tasks, i.e. initiated by a teacher who shares content with individual learners or the whole classroom (see table 2). Teachers can either share the whole screen of an application or an element (e.g. an exercise). This results in the following tasks:

(1) Sending an application from a learner's tablet to the projector (e.g. sharing a learner's spreadsheet to correct it with the class)
(2) Sending an element from a learner's tablet to the projector (e.g. sharing a learner's answer from an exercise to the video-projection)
(3) Sending an application from the teacher's tablet to a learner's tablet (e.g. sharing the spreadsheet correction with a learner)
(4) Sending an element from the teacher's tablet to a learner's tablet (e.g. sharing an exercise correction with a learner)
(5) Sending an application from a learner's tablet to all learners' tablets (e.g. asking all learners to correct a learner's spreadsheet)
(6) Sending an application from a learner's tablet to all learners' tablets and the video-projection (e.g. sharing an interesting learner's spreadsheet with other learners and analyzing it with the class)
(7) Sending an element from a learner's tablet to all learners' tablets and the video-projection (e.g. sharing an interesting learner's answer to an exercise with other learners and analyzing it with the class)

(8) Sending an application from all learners' tablets to the video-projection (e.g. comparing all learners' spreadsheets with the class)
(9) Sending an element from all learners' tablets to the video-projection (e.g. comparing all learners' answers with the class)

4.2.2 Remote control. In order to manage activity flow, teachers perform remote control tasks on learners' devices. These tasks can aim at ensuring progress throughout the activity and making sure learners do not get stuck, managing learners' attention or explaining/managing the content projected to the whole class. We have no a priori about the devices that teachers will use when performing these tasks. For this reason, the lines relating to the source devices for remote control tasks are empty in Table 2.

To manage learners' progress in the activity, teachers have to be able to control the content of tablets at individual or class level.

(10) Take control of content of one learner tablet (e.g. unlocking a new activity for a learner)
(11) Take control of content of all learner tablets (e.g. unlocking a new activity for all learners)

Teachers need to manage learners' attention, and tablets can be distracting. Therefore, these tasks are performed by controlling device output, namely by turning the screen or sound on and off.

(12) Turn off sound on all learners' tablets
(13) Turn on sound on all learners' tablets
(14) Turn off screen on all learners' tablets
(15) Turn on screen on all learners' tablets

The ability to remotely control the video-projection provides teachers with opportunities for intervening from anywhere in the classroom.

(16) Application switching on video-projection (e.g. switching from a spreadsheet)
(17) Content selection on video-projection (scrolling from one exercise to another on the video-projection)

5 STUDY 2: INTERACTION STRATEGIES FOR MANAGING DEVICES IN CLASSROOMS.

Based on the device management tasks defined in the previous section, we conducted a second study to understand *what are meaningful interaction strategies for managing multi-device classrooms?* The study involved teachers in a pseudo-ecological setting in the most common configuration of devices in French classrooms: individual tablets for learners and a video-projector hooked to a PC (or a tablet) controlled by the teacher. We introduced a smartwatch as a controller, alongside the teacher's tablet in order to further understand how teachers could remote control a complex device ecosystems from anywhere in the classroom.

Our approach is broadly inspired by elicitation studies [55]. Such studies are useful for revealing meaningful mappings between referents (commands to perform) and actions (e.g. gestures) by computing an agreement score to identify consensus among participants [54]. But elicitation studies also come with limitations. Firstly, they tend to omit the reasons and processes that led participants to propose interactions, focusing rather on "naturalness" or "guessability". The interactions derived from such studies risk optimizing local agreements among participants, at the cost of overall coherence of the interaction vocabulary. Secondly, variations of Wobbrock's agreement rate [54] are often used in elicitation studies, e.g.,[36, 51, 55] However, for complex interactions the number of combinations explodes and classical agreements become meaningless for analysis purposes.

Because device management tasks involve multiple devices, as well as likely interaction sequences, command selection, and authentication, we decided to focus on understanding the **intentions** and interaction **strategies** of teachers rather than "intuitive" or "guessable" interactions. The analysis also tackled the rationale of gestures, *i.e.* the way participants explained and motivated their choice of interaction.

		1 Application from learner's tablet to video projection	2 Element from learner's tablet to video projection	3 Application from teacher's tablet to learner's tablet	4 Element from teacher's tablet to learner's tablet	5 Application from learner's tablet to learners' tablets	6 Application from learner's tablet to all devices	7 Element from learner's tablet to all devices	8 Application from learners' tablets to video projection	9 Element from learners' tablets to video projection	10 Taking control of learner's tablet	11 Taking control of all learners' tablets	12 Mute all learners' tablets	13 Unmute all learners' tablets	14 Turn on all learners' screens	15 Turn off all learners' screens	16 Application switching on video projection	17 Element selection on video projection
Action	Content sharing	■	■	■	■	■	■	■	■	■								
	Remote control										■	■	■	■	■	■	■	■
Object manipulated	Element		■		■			■		■	■	■						■
	Application	■		■		■	■		■								■	
	Device												■	■	■	■		
Source device ● →	Tablet (learner)	■	■			■	■	■										
	Tablet (teacher)			■	■													
	Tablet (all learners)								■	■								
	Video projector																	
	Computer																	
	Tangible																	
Target device → ◉	Tablet (learner)			■	■						■							
	Tablet (teacher)																	
	Tablet (all learners)					■	■	■				■	■	■	■	■		
	Video projector	■	■				■	■	■	■							■	■
	Computer																	
	Tangible																	
Target users	Learner			■	■						■							
	Group																	
	Class	■	■			■	■	■	■	■		■	■	■	■	■	■	■

Table 2. Tasks representative of teachers' device management activities in the classroom.

5.1 Study set-up

We picked a typical digital classroom configuration composed of tablets for learners and teachers, and a video-projector [35]. Previous observations of tablets as orchestration controllers showed that they tend to be too cumbersome to carry and that teachers leave them at their desk [30]. This raises the question of which interactive controller would be best suited to support device management. Smartphones are already widely available to teachers and could be good candidates. Yet, informal discussions with teachers suggested that they considered them to be too personal for "live" use in classrooms. Smartphones also require one hand and can be complex to put in a pocket. Combined to negative experiences with tablets, this suggested that a wearable control device would be an interesting form factor for managing devices. This led us to introduce a smartwatch for teachers to control devices from anywhere in the classroom.

To recreate an ecological but controlled environment the study was conducted in a classroom of a French University. The room selected had a layout widely used in French high schools similar to the layout used in most classrooms observed in study 1: rows of tables for two learners facing a whiteboard and a video-projection screen (Fig. 3). The ETIC 2019 report [35] describing digital equipment is France shows that 21.7% of secondary school students have access to computers (desktop or laptop) or tablets and approximately 40% of classrooms are equipped with a video-projector.

5.2 Participants

20 participants (8 female, 12 male), aged between 23 and 63 (M=37.7, SD=10.9) were recruited. All participants were teachers with experience in using digital devices in their classrooms. 14 of them regularly used devices

Fig. 3. Teacher (red) and observer (blue) trial task 9. Left: initial state; Right: final state. Spatial set-up: learners' tablets on learners' tables, teacher's tablet near the computer, video-projection, observer's table left to the observer.

during classes. They reported using devices in their everyday life (16 of them use a smartphone and a computer, laptop or PC daily) but only a few of them (5) had previous experience with smartwatches.

Participants mostly reported using digital tools frequently in class (14 participants use digital devices frequently, 6 use digital devices from time to time). Devices used in the classroom were mainly video-projectors (all participants frequently) and computers (18 participants frequently, 2 participants from time to time). On the other hand, participants made little use of tablets in class (2 participants from time to time, 18 participants never). Participants never used a smartwatch in their classes.

Outside classrooms, participants used a computer and a smartphone daily (19 and 16, respectively, while 4 participants did not possess a smartphone). Participants used a tablet regularly (6) and from time to time (10). On the other hand, only 3 participants used a smartwatch every day, while 2 participants used one from time to time, and 15 had never used one before.

These results highlight the infrequent use of tablets and smartwatches for teaching purposes. By having only two participants with experience with tablets in classrooms and none using smartwatches in classes, we limited the legacy bias due to "experience with prior interfaces and technologies" [37].

5.3 Apparatus

Participants had access to 7 devices: a smartwatch, a teacher's tablet, 4 tablets on learners' tables in front of the teacher, and a video-projector on a whiteboard connected to a PC. They could freely move and combine devices when performing gestures.

The smartwatch was a Samsung Galaxy Watch with a 1.3" screen, a rotating bezel, and two physical buttons running on TizenOS. The tablets were Samsung Galaxy Tab S2 with a 8" screen, physical buttons (sound, power, home) running on Android. The video-projector used had a ratio of 4/3 (75", 1280x960px).

5.4 Interaction vocabulary

We defined a set of 25 atomic gestures illustrated in Figures 4 to 6 inspired from Brudy et al.'s *Cross Device Interaction* paper [7], where authors list input modalities according to interaction goals. These gestures involve three devices: smartwatch, tablet, and video-projector (generally used on a whiteboard). We decided to use

established gestures and focus on the intentions that participants put behind these gestures. The intentions and gesture combinations enabled us to better understand participants' strategies when performing the tasks.

5.4.1 Gestures on smartwatch. We defined 13 smartwatch gestures (Fig.4). These gestures are inspired from the existing interaction vocabulary on the Samsung Galaxy watch: swiping, touching, pinching, shaking, moving the wrist, hiding the screen, pressing buttons or turning the bezel. A gesture leveraged the smartwatch and a tablet by bringing them into proximity.

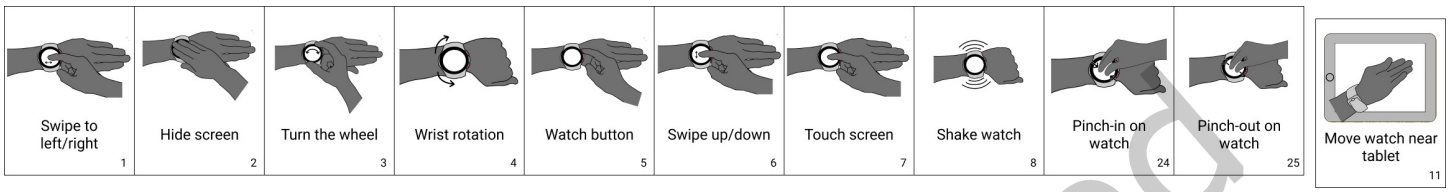

Fig. 4. Smartwatch gestures proposed to participants

5.4.2 Gestures on tablet. We defined 13 tablet gestures building upon the existing interaction vocabulary with tablets: touching an element, moving an element on their surface, swiping, pinching in and out, pressing physical buttons, and flipping the tablet (Fig.5). Three gestures with tablets involved another device: bringing a smartwatch up to a tablet, bringing the tablet within the proximity of another tablet or aiming with it.

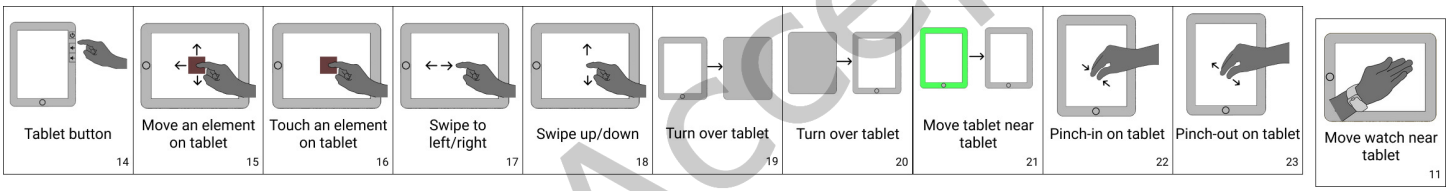

Fig. 5. Tablet gestures proposed to participants

5.4.3 Gestures with video-projection. Among available devices in classrooms, the most commonly used is the video-projector, used on a whiteboard or projection screen. We considered video-projectors to be passive devices, and decided to leave out interactive whiteboards for simplicity purposes. As a result, there is no direct interaction with video-projectors but only indirect interaction with a smartwatch or a tablet.

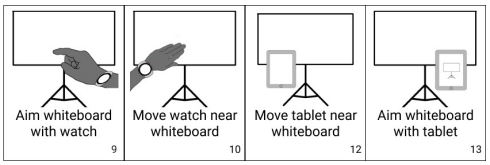

Fig. 6. Video-projection gestures proposed to participants

For richer interactions, we included two modifiers: double tap and long tap that could be used in association with any gesture. The atomic gestures could be combined to form interaction sequences. We limited possible combinations to a maximum of six gestures as in [47].

5.5 Procedure

Figure 7 summarizes the protocol followed: The study started by asking participants to fill in a questionnaire to collect demographic data and information about their use of digital tools in and outside the teaching context (Step 1). Then the study, its procedure and its purpose (Step 2) were explained. It was followed by a presentation of gesture cards, and asking participants to perform the gestures illustrated to ensure that each card was understood (Step 3).

For each task we repeated the following procedure (with a randomized order of tasks for each participant):

4.a We read the storyboard text and showed a short animation illustrating the effect on the devices in the classroom.

4.b Participants chose a set of gestures (from 1 to 6 cards maximum) to perform the task (Fig.8.b). We asked them to think aloud when choosing their cards to explain their intentions.

4.c Participants performed the interaction they preferred with the devices.

4.d Participants rated the usefulness of the task, whether they understood it, the ease of performing gestures, and their satisfaction with the gestures they chose (Fig.8.c). We captured their answers by taking a picture of their answer sheet.

Each task was presented as a storyboard (Fig.8.a), to further illustrate the tasks and to anchor participants in the situation, a short animation was also presented, with elements appearing and disappearing on the devices involved (Fig.3). The storyboard and the animation had three states:

- Initial state with the teacher's objective (e.g. sharing content from a learner's tablet to the video-projection)
- Transition state
- Final state (e.g. with content shown on a learner's tablet and on the video-projection)

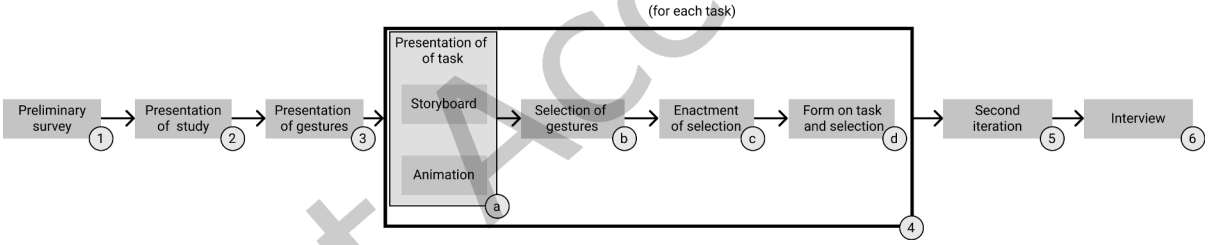

Fig. 7. Study procedure

After going through all the tasks, participants had the opportunity to come back to their original propositions (Step 5). Our goal was to improve internal consistency in participants' answers by letting them review their initial answers.

A short exit interview with each participant concluded the study. It covered the reasons behind the strategies they adopted, the interactions they considered unsatisfactory, and finally the limitation related to the set of available gesture cards (Step 6).

5.6 Analysis Method

Given the complexity of our tasks and the possibility of combining gestures, rather than computing a simple agreement score, our analysis is structured around four goals:

(1) **Assess the relevance of our tasks.** We asked participants two questions: *"how understandable is the task?* and *"how useful is the task?"*. Participants answered on a 7-point Likert scale from totally useless (or not understood) to totally useful (or understood).

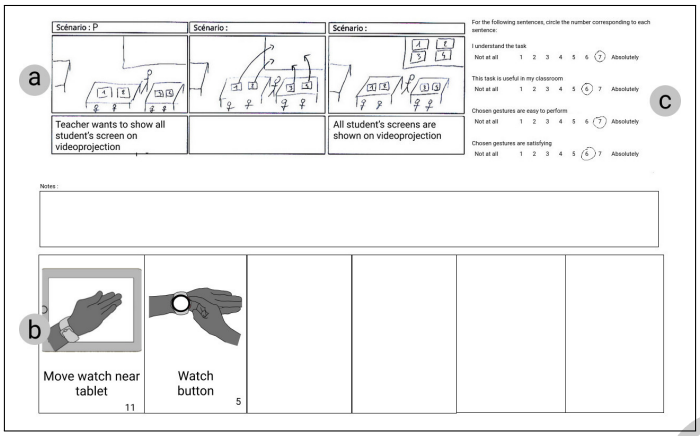

Fig. 8. Example of an answer sheet (including 3 parts a,b,c) filled in by participant 3 for task 8

(2) **Understand the structure of gesture sequences** proposed by participants. We conducted an analysis focused on sequence length, recurring gestures, and most frequent sequences. Our goal was to identify recurring gesture sequences proposed by participants.
(3) **Understand the choice of devices used** to perform the tasks. We analyzed the devices used for each category to identify those most often used and the most frequent combination of devices for the tasks. Our goal was to identify which tasks led participants to use a given device or a combination of devices.
(4) **Understand the rationale** behind the sequence of gestures focusing on **strategies** proposed by participants. A strategy is defined as a combination of intentions associated with gestures to perform the task. Our goal was to identify recurring intentions and to gather insights into how participants constructed their strategies depending on the tasks.

For the last analysis focusing on strategies, we asked participants to think-aloud during the experiment. This helped us, after the experiment during the analysis phase, to determine the intentions behind gestures. We first built a categorization of intentions from a pilot study with two participants. After iterations among co-authors, we grouped several intentions to simplify the categories. We obtained nine final categories: (**TC**) Trigger Command, (**SS**) Source Selection, (**TS**) Target Selection, (**TE**) Transport of Element, (**ES**) Element selection, (**C**) Control, (**VoC**) Validation of Control, (**VC**) Validation of Command, and (**CC**) Command Choice.

The *Trigger Command* intentions correspond to action 'verbs' of tasks (sharing for tasks 1 to 9, taking control for tasks 10 and 11, turning off/on for tasks 12 to 15, and navigating for tasks 16 and 17). We then tagged the gestures of each sequence with an intention. Using the example of Figure 8, for task 8 (project the application screen from a learner's tablet to the shared screen), the list of intentions associated with the sequence of gestures produced by participant 3 was Target selection, Trigger command (carried out directly on the learner's tablet).

6 RESULTS

6.1 Relevance of the tasks

Overall, participants perceived the tasks as relevant for management of digital devices in the classroom (Fig. 9). The mean of perceived usefulness for tasks is 6.0/7, with a standard deviation of 1.6.

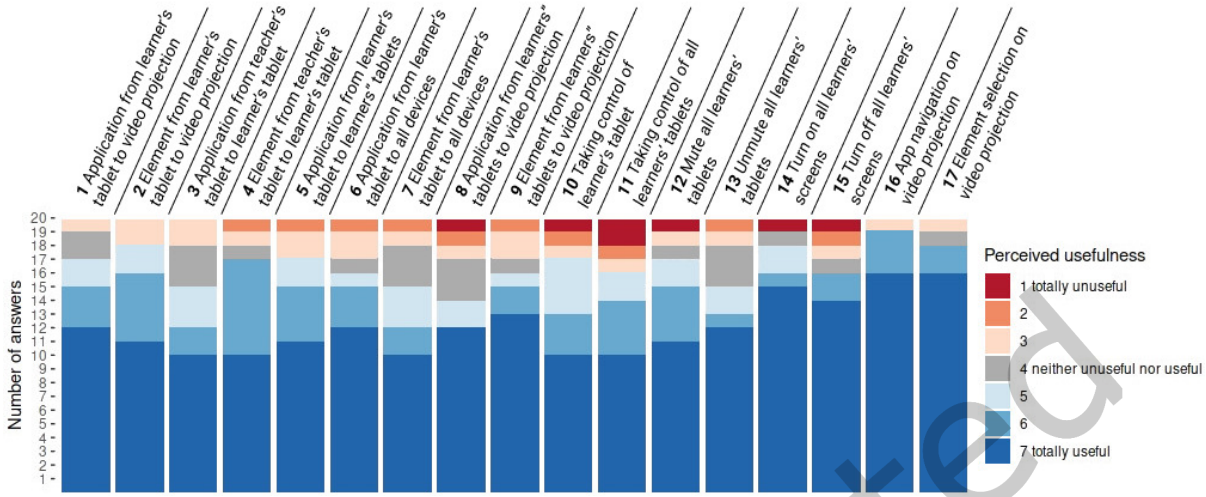

Fig. 9. Perceived usefulness of tasks

6.2 Overview of participants' propositions

The complexity of the tasks led to a large number of gesture combinations. Participants generated a total of 340 sequences of gestures while performing the tasks, of which 203 were different, with no sequence standing out as frequent. Participants proposed only 23 sequences more than once, and the most frequent sequence (moving a tablet next to another tablet with a single gesture, Fig. 5, gesture 21) was proposed 8 times.

Gesture sequences varied from one to six gestures. 287 out of 340 propositions were small sequences of two gestures (124/340), one gesture (86/340), and three gestures (77/340). The last 53 propositions were spread among sequences of 4, 5, and 6 gestures. Participants preferred proposing short sequences, and explained that short sequences were easier to perform and memorize.

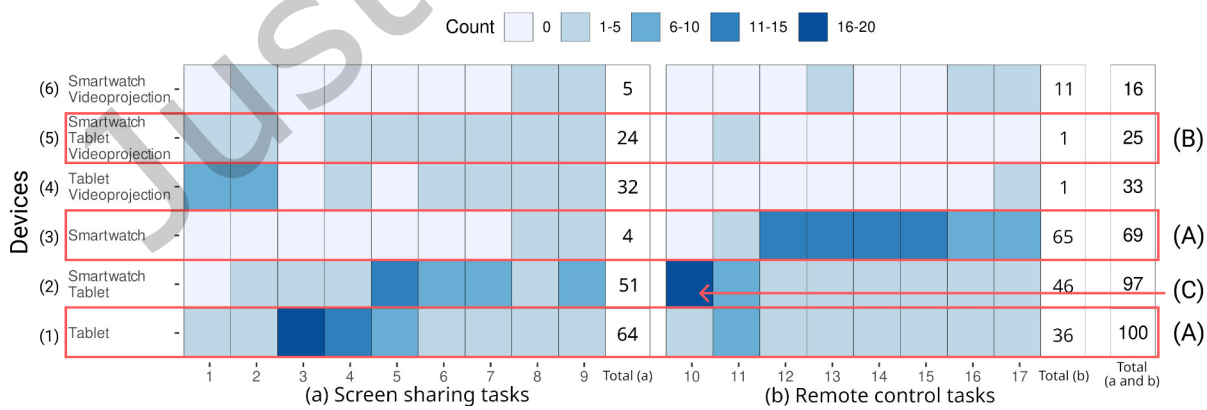

Fig. 10. Devices used for each task

We observed different device combinations (Fig. 10). In half the propositions (169/340, Fig. 10.A), participants used only one device. The combination of three kinds of devices (tablet, smartwatch, and video-projector) was hard to implement, and participants proposed this combination in only 25 out of the 340 propositions (Fig. 10.B). These observations argue for keeping device composition to a minimum: participants preferred using only one device in most cases. When use of a single device was insufficient, participants combined two devices to disambiguate (e.g. when pointing to another device, such as the video-projection, to select a target for application sharing). The combination of multiple kinds of devices can be used to provide specific rights, for instance authenticating teachers on learners' devices (e.g. when using proximity between a smartwatch and a learner's tablet to unlock the tablet in teacher mode, Fig. 10.C).

We identified a total of 47 different strategies, *i.e.* a set of intentions linked to gestures, to perform tasks. Participants proposed seven strategies more than 10 times (Fig. 11.I). Two strategies stand out:

(1) Directly triggering the command associated with the task (TC:109/340, Fig.11.1) This was the simplest strategy which worked well for remote control tasks, such as shutting down tablet screens by hiding the smartwatch's screen (gesture 2, TC), as well as for content sharing, **e.g.** putting the teacher's tablet on a learner's tablet to share the teacher's application (gesture 21, TC).
(2) Selecting a target and triggering a command (TC;TS:61/340, Fig.11.3), such as pointing to the video-projection with the tablet (gesture 13, TS) and performing a swipe up to share the teacher's application on the video-projection (gesture 18, TC).

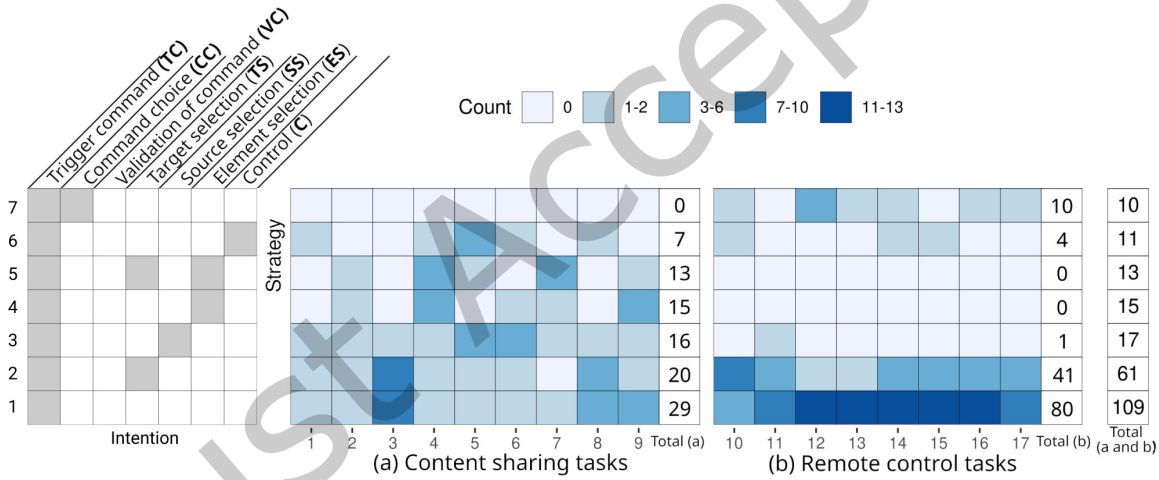

Fig. 11. Most popular strategies for each task. For clarity, 86 strategies that were proposed less than ten times are removed.

Other notable strategies include:

(3) Selecting a source and triggering command (TC;SS:17/340, Fig.11.2), such as using proximity between the teacher's tablet and a learner's tablet (gesture 21, SS) and performing a swipe up with the teacher's tablet to share the learner's application on the video-projection (gesture 18, TC).
(4) Selecting the element to transfer and triggering command (TC;ES:15/340, Fig.11.4), such as selecting the element on the teacher's tablet (gesture 16, EC) and transferring it to a learner's tablet by using proximity between tablets (gesture 21, TC).
(5) Selecting the element to transfer, selecting target, and triggering command (TC;TS;ES:13/340, Fig.11.5), such as selecting an element on the teacher's screen (gesture 16, ES), pointing to the video-projection with

the tablet (gesture 13, TS) and performing a swipe up to share the element on the video-projection (gesture 18, TC).

(6) Taking control of device and triggering command (TC;C:11/340 , Fig.11.6), such as using proximity between smartwatch and tablet (gesture 11, C) and using a smartwatch's button to validate control of the learner's tablet (gesture 5, TC).

(7) Selecting command and triggering command (TC;CC:10/340, Fig.11.7), such as hiding the smartwatch's screen to power learners' screens (gesture 2, CC) and clicking on the smartwatch's button to validate the action (gesture 5, TC).

Findings for gesture strategies:

- Participants suggested a wide variety of gesture sequences, with little consensus.
- Participants proposed short gesture sequences, varying from 1 to 3 gestures (287/340 or 84.4%).
- Participants preferred using simple combinations of devices (one device only for 169/340, two devices for 146/340).
- Participants proposed identical strategies, although the underlying sequences of gestures differed. Participants proposed 7 strategies more than 10 times, with 2 strategies standing out.

6.3 Analysis by task category

6.3.1 Content sharing. Tasks related to content sharing involved selecting the source and target devices, as well as selecting the content to share (an application or an element). We did not observe any overarching strategy for these tasks (Fig.11.a), although participants proposed most frequently the strategies Trigger command and Source selection + Trigger command. They explained in the interviews that they tried to maintain a form of inner consistency depending on the sharing context (source device, target device, element to share), by keeping the same gesture/vocabulary of gestures for similar intentions and tasks. For instance, participant 1 decided to use gesture 11 (move watch near tablet) to select a tablet as a source for all the sequences.

Device used. All content sharing tasks involved a tablet, making it the most used device, either alone (64/180) or combined with other devices (51/180 with smartwatch, 32/180 with video-projection, and 24/180 with smartwatch and video-projection (Fig.10, lines 1, 2, 4, and 5). Participants found that combining tablets and a smartwatch was useful for content sharing (**e.g.** P4: "The tablet and the smartwatch complement each other"). For a majority of participants, a smartwatch alone seemed insufficient for sharing content, due to its narrow screen space for content display and selection (only 4 out of 340 propositions, Fig.10 line 3).

Source and Target selection. In most cases (112/180), participants either selected a target device (69/180) or a source device (62/180), with no clear preference for either (Fig.11.II). Participants selected both a source and a target device in a few cases (19/180). As an example, for task 6 (sharing the application from a learner's tablet to other learners' tablets and the video-projection), six propositions involved selecting only the target devices, four only the source, and six a combination of targets and source.

When a target was selected explicitly with a specific gesture, such as bringing one tablet closer to another (Figure.5, gesture 21) or aiming towards a device (Figure.6, gestures 9 and 13), the source was selected implicitly, and vice versa when the source was selected explicitly. This *implicit selection* is performed by:

- Proximity of the teacher to a device: "My watch is nearby, so it detects that I'm here" (P7), "I use the proximity of the watch for distribution purposes" (P2) (implicit selection of source).
- The device currently used by the teacher, i.e. the one with the element to share (implicit selection of source).
- Device positioning: "If the learner's tablet is on top, it goes to the teacher [...] If the teacher's tablet is on top, it goes to the learner" (P9) (implicit selection of target or source according to user).

In addition, for tasks where a specific element was shared (**i.e**, tasks 2, 4, 7, 9), participants included a gesture to clearly select the element to share (in 56 out of 100 propositions). The gesture used to select an element was mainly touching the element to select on the tablet (Figure.5, gesture 16).

Strategies. Participants proposed sequences varying from 1 to 3 gestures for content sharing. Task 3, sending an application from the teacher's tablet to a learner's tablet, had the most propositions with one gesture (Fig.11). Eight participants moved the teacher's tablet next to a learner's tablet (gesture 21, Fig.5), using proximity of devices to implicitly select both source and target.

Participants tried to keep the same gestures mapped to their intentions when selecting the source and target involved in the tasks "Each time I try to have the same gestures" (P17), "I try to have the same kind of gestures depending on the source and target" (P16). Despite the lack of consensus among participants, two recurrent strategies emerged for content sharing according to the object manipulated:

(1) For sharing of a specific element (tasks 2, 4, 7, 9): the teacher **selected the source** to share **and/or** s/he **selected the element to share**, then s/he **selected the target** where the sharing would be performed, and finally s/he triggered the **sharing command**.
(2) For sharing of an application (tasks 1, 3, 5, 6, 8): the teacher **selected the source** device **and/or** s/he **selected the target** of the task, and finally s/he **triggered the content sharing command**. This sentence could be augmented with other intentions. For example, the teacher could perform a **control command** (to grant the teacher's right on the device) combined with **source selection** to act directly on a learner's device or could add a **validation command** when performing the sharing.

Findings for content sharing tasks:

- Participants proposed sequences varying from 1 to 3 gestures (average sequence size of 2.7 gestures). The strategy most frequently proposed was a single trigger command (one gesture), while the second most frequent combined 2 gestures: Source selection + Trigger command or Target selection + Trigger command.
- Participants did not display a preference for picking the source or the target first. However, they picked one of the devices (source or target) implicitly in 89% of all cases.
- Participants relied on tablets for content sharing, either alone or in combination with other devices.
- Depending on what participants shared (a screen element or the whole application screen), they proposed different strategies.

6.3.2 Remote control. Remote control (tasks 10 to 17) involved one device (the target device), thus making them simpler. As a result, two strategies, Trigger command, and Source selection + Trigger command were extensively proposed. For a finer analysis, we split remote control tasks into three subcategories to obtain: control of tablets' content, physical control of the devices, and control of content on the video-projection.

Controlling content on learners' tablets (tasks 10 and 11). When participants had to take control of content on one tablet or on all learners' tablets, they mainly used a combination of a smartwatch and a tablet (24/40, Fig.10 line 2) or tablets alone (13/40, Fig.10 line 1).

Participants (i.e. teachers) preferred to act directly on learners' tablets rather than on their own tablet (especially for task 10), with thirteen participants expressing the need to maintain teacher-specific control on learner content. This reveals a need for finely managing access/control rights when performing actions on devices. To enable teacher-specific actions, participants envisioned two strategies:

(1) Using a teacher-specific device (tablet or smartwatch) to unlock teachers' rights on learners' tablets through proximity, by moving their device closer to the target tablet (11/20 participants).

(2) Using additional gestures to confirm the device unlocks, such as touching the smartwatch's screen to confirm after performing an unlock gesture on the tablet (2/20 participants)

Controlling device screens and audio (tasks 12-15). To manage learners' attention, teachers sought a way to control the output modalities of devices: switching on or off the screens of learners' tablets and muting/unmuting tablets to avoid distracting audio bursts. In 47 out of the 80 propositions, participants used the smartwatch alone to perform these tasks. Participants mainly used two strategies with these tasks: a single gesture to trigger the command (48/80) or selecting the target with a gesture and triggering the command with another gesture (15/80), (Fig.10).

In interviews, participants emphasized the need to create "meaningful gestures"(P17) and "small, quick and easy ways to perform gestures" (P18). They proposed reusing gestures they knew: "I use similar gestures for volume control"(P2), i.e. placing a hand on the smartwatch's screen to turn on or off learners' screens and using the smartwatch's buttons to mute and unmute tablets.

Controlling the video-projection (tasks 16 and 17). Participants found the two tasks related to video-projection control (app navigation and element selection on video-projection) to be the most useful (Fig.9). They used either the smartwatch alone (16/40) or the smartwatch combined with the video-projection (10/40 Fig.10, lines 3 and 6). Participants mainly used two strategies:

- Using a smartwatch alone to perform a single gesture for video-projection control (TC);
- Using a combination of smartwatch and video-projection to select the target (TS) (by pointing the video-projection or by bringing the smartwatch closer to the video-projection) and to perform the control command (TC) on the smartwatch.

Few participants proposed using a tablet alone (7/40, Fig.10, line 1) or combined with other devices (7/40, Fig.10, lines 2,4, and 5). Teachers needed to control the video-projection from anywhere in the classroom, and tablets were too cumbersome to carry, as explained in P17: "I rather like to use the watch when I'm in the row".

Findings for remote control tasks:

- Participants mainly used the smartwatch (alone or combined with other devices) for remote control tasks.
- Participants mostly used simple strategies (directly triggering the command was the most frequent).
- Participants replicated gestures to control remote devices, either ones they already knew or ones that they had devised.
- Participants expressed a need for managing access rights on learners' tablets.
- Teachers' devices (smartwatch or tablet) can be used as authentication devices.

7 DISCUSSION

Through our first observational study, we identify five themes for device management in classrooms. The most critical themes are pedagogical interventions, attention management, and activity management. From an interaction perspective, they relate to two categories of tasks: sharing content and controlling remote devices. Such tasks have not been studied in orchestration research, and existing products only support them partially. Few systems support finely controlled content sharing with learners, something particularly easy with paper. And remote control of devices is currently limited to screen or audio outputs.

Our second study highlighted that remote control tasks offer the most opportunities for design interventions. Participants often chose to perform them with a single gesture (directly triggering a command). We observed a consensus on using the smartwatch alone or combined with another device. Content sharing tasks are more complex to design for, as they involve more parameters such as picking the source and target devices, and often

involve authentication. Based on our two studies, we outline opportunities for design, and discuss challenges that are still to be solved, as well as some limits of our approach.

7.1 Design Opportunities for Multi-Device Management in Classrooms

7.1.1 Reducing cognitive load for multi-device management. Simple actions triggered on a smartwatch can be performed quickly without much cognitive load, i.e. as peripheral interactions [19]. This enabled teachers to carry on with their activity with little attention dedicated to the action, As noted by P4, "you don't need to stop to perform the action and you can continue your class". Participants favored short sequences of one or two gestures, especially for remote control tasks, keeping the gestures simple enough to perform them with little cognitive load. In this context, many participants appreciated smartwatches (P4, P7, P17) for remote control tasks, e.g. "The watch is convenient if you're in the back [of the room, or] if you don't have access to your tablet" (P4).

The gestures most suggested were hiding the screen, using side buttons, and pointing. These gestures were linked to attention management tasks, and aimed at facilitating pedagogical interventions, for example controlling the screens and audio learners' devices or controlling the projection. These gestures could also be coupled with time or activity management features specific to watches, such as the chronometer to facilitate management of class progress and time constraints.

7.1.2 Enabling control from any device. Our second study suggests that teachers' actions are conditioned by the devices they have at hand. i.e. if teachers already have a learner's tablet in their hand or in close proximity, it makes more sense for them to use it to control or share content rather than to use their own device. For other types of remote control or content sharing tasks, they suggested performing them on their tablet or their smartwatch depending on what was closest and most convenient. This suggests that controls should be replicated rather than device-specific.

7.1.3 Supporting authentication and role management. As participants relied equally on teacher and learner devices, they stressed the importance of role management. Teachers want to be able to access administrative features on the learners' tablets but do not want the learners to have access to them. These features can be particularly useful for showing the solution to an exercise or for solving technical problems. Most participants, when using a learner's tablet, added an authentication mechanism to temporarily access teachers' rights. The smartwatch or the tablet could be used as an authentication device, allowing the design of systems where teachers can quickly perform privileged actions on learners' devices without going through more cumbersome authentication methods (code, gesture on the device). One approach could be to use the proximity between the teacher's smartwatch and the tablet, as proposed by Kharrufa [28] or Chen [8]. Alternatives that do not require extra hardware would also be very relevant.

7.1.4 Supporting collaborative gestures and delegation of interaction. We observed that it was easier for teachers to select a device close to them (for example by bringing one tablet next to another) than distant devices. Our observation is concordant with studies on how users pair devices together [9]. Selecting a device from a distance remains a challenge, and it is still challenging to develop accurate pointing gestures at a distance. Rather than pushing for finer controls by teachers, an alternative would be to involve learners more in the management of activities and devices.

Collaborative gestures [31, 38, 42] could mitigate the limitations of remote pointing or remote selection in classroom contexts. Teachers could initiate an interaction sequence that would be finished by learners, e.g. teachers could initiate a throw gesture, finished by a catch gesture on the learners' side. Teachers and learners could perform gestures synchronously, e.g. tapping together on an unlock button to access specific content.

Teachers could also perform delegation gestures. For example, a teacher could temporarily enable content sharing for learners to allow them to push their work on the video-projection. In study 2, we observed participants

split the selection of multiple devices into multiple selections of unique devices. Such a strategy implies performing a large number of gestures, and is time-consuming. Delegation of selection to learners should be possible by asking learners to perform an action or gesture on their tablet after performing some form of "temporary unlocking". These gestures imply joint studies of teachers' and learners' actions.

7.2 Challenges for device management tasks in classrooms

7.2.1 Implicit interactions for selecting devices in classrooms. We observed teachers combining implicit [27] and explicit interactions to select devices. In some instances, the selection was an explicit gesture that teachers deliberately performed. As an example of mixing implicit and explicit interaction, when teachers aim at the video-projection with a tablet to push content: the target is explicitly selected through aiming, whereas the tablet containing the content is selected implicitly when the teacher selects content by touching an element on the screen.

In 90% of content sharing tasks, participants did not select the source explicitly, i.e., they performed an implicit selection. This happened when there was only one device as the source, whereas selecting target devices out of many possible ones involved explicit selections.

Supporting implicit interaction for source selection would shorten interaction sequences. However, implicit interaction increases the potential for gesture collision and accidental summoning [17]. Teachers perform many gestures for communication purposes in the classroom, and some could be interpreted as commands by recognition engines. Recovering from such misinterpretation errors during a pedagogical activity would be detrimental to the activity. To mitigate such confusion, participants often introduced validation steps, such as validating a sharing command on the smartwatch after pointing towards the video-projection.

Investigating how explicit and implicit interactions could be combined to facilitate activities while preventing errors is a promising area for future research on connected classrooms, especially as they incorporate more devices or sensing technology. Here further research on identifying the most critical actions that teachers perform in classroom, and the ones that are the most difficult to recover from (e.g. setting up an activity, giving access to documents or corrections), would help to introduce validation steps or error recovery strategies where most relevant.

7.2.2 New interaction metaphors for multi-device management. The interaction metaphors used by traditional learning platforms are still strongly linked to the personal computing era. Elicitation studies provide generative insights into how people could transfer their existing knowledge and assumptions about interactions to new set-ups. However, as the environment increases in complexity, new interaction metaphors need to emerge. In its time, Rekimoto's pick and drop [43] sparked the imagination of what seamless information spaces could be, in line with earlier visions of ubiquitous computing.

In our second study, participants hinted at new metaphors. For example, to transfer content from a learner's tablet to the video-projection (tasks 1 and 2), some participants moved a mobile device close to the learner's tablet, thereby storing it on their mobile device, before transferring it to the projector when they moved close to the latter. Making, the smartwatch a physical container to transfer data from a device to another. In the classroom, this could be used when teachers want to transfer an exercise to a learner, or when the teacher wanted to show the content of a student tablet on the video-projector to support a discussion or correction. In such a case, the watch offers the advantage of freeing the teacher's hands.

This is reminiscent of work on ubiquitous input devices (see [3]) supporting or augmenting gestures with different functions according to context and other devices associated with them. However, this was carried out with only a few participants. Developing interaction and document management metaphors suited to the classroom environment will require more consistent efforts, from interaction modalities to software and hardware support, not to mention the learning aspects.

7.3 Limitations

7.3.1 Considering broader multi-device configurations and orchestration set-ups. We focused on supporting teachers managing multiple tablets in their classroom. This is a very specific aspect of device management and only covers a limited number of orchestration scenarios. Observing the same sequence of lessons with teachers of the same discipline (mathematics) improved the robustness of the observations but offers a limited view of critical tasks in classroom. This type of study should be pursued with teachers working in other disciplines, levels, schools, regions, etc.

We proposed five design dimensions for structuring device management tasks: the task category (content sharing or remote control), the object manipulated (element, application, device), the target user (learner, group, class), and the source and target devices. More dimensions could be added to consider other classroom configurations, different learners or pedagogical approaches to support. For instance, we focused our analysis on two tasks, which are the most critical for instructional management. We left out elements related to class guidance, articulating content, attention and flow. These are linked to orchestration challenges with progress monitoring [44] but also personalizing activities to learners. We also did not consider class configuration that involved group work, and assumed that only a teacher could manage devices. In collaborative contexts, sharing could take many forms and would require more control from learners. Finally more devices beyond tablets could be considered according to teachers' practices.

7.3.2 From the lab to the wild. For our second study, we sought to find a balance between the lab and a more representative environment. We recruited experienced teachers, and conducted the study in a realistic environment but without learners and with a subset of devices: individual tablets for learners and a smartwatch, a video-projector hooked to a PC and a tablet for teachers. Involving teachers and learners in ecological conditions would enable us to investigate in more detail how interaction strategies can be integrated within the flow of a class session, without overloading teachers or disturbing learners.

Our choice of introducing a smartwatch was guided by teachers considering smartphones to be too personal for "live" use in classroom, and tablets to be too cumbersome to carry. However, the choice of introducing yet another device may make device management more challenging. One possible next step towards further understanding how devices could be managed in real classrooms would be to conduct less controlled studies, in-situ and with existing devices, or with dedicated tangible remotes with a limited set of buttons triggering predefined actions.

8 CONCLUSION

We conducted two studies to understand the needs and practice of teachers in managing multi-device classrooms. Through an observational study of nine classes, we identified challenges related to device management in conducting pedagogical interventions, configuring the devices, managing the flow of the classroom activities, and managing learners' attention. We built upon these observations to identify five categories of multi-device management for orchestration goals.

We derived a set of 17 tasks representative of teachers' device management activities in the classroom, grouped into two categories: sharing content across devices and remote control of devices. We conducted a follow-up situated elicitation study to understand teachers' interaction strategies when performing these device management tasks in a specific classroom configuration. Participants found the tasks useful. While participants proposed a wide variety of gesture sequences, we identified seven major strategies.

For content sharing tasks, we found that (1) participants proposed interaction sequences of three gestures on average; (2) tablets were central to performing sharing tasks, and that the proposed strategies depended on what participants shared (a screen element or the whole application screen); and (3) participants selected one of the devices involved in the interaction implicitly in almost 90% of cases.

For remote control tasks, we found that (1) participants heavily relied on the smartwatch, either alone or combined with other devices, proposing simple strategies; (2) participants replicated gestures to control remote devices; and (3) teachers preferred to use their devices (smartwatch or tablet) as authentication devices to temporarily grant them rights on learners' tablets.

Finally, we identified opportunities for design, ranging from reducing cognitive load in remote control tasks, supporting lightweight authentication or collaborative gestures, and challenges to be considered for device orchestration such as implicit interaction and the need for new metaphors.

REFERENCES

[1] Richard Arthur and Dan R Olsen Jr. 2011. Xice windowing toolkit: Seamless display annexation. *ACM Transactions on Computer-Human Interaction (TOCHI)* 18, 3 (2011), 1–46.

[2] Gilles Bailly, Dong-Bach Vo, Eric Lecolinet, and Yves Guiard. 2011. Gesture-Aware Remote Controls: Guidelines and Interaction Technique. In *Proceedings of the 13th International Conference on Multimodal Interfaces* (Alicante, Spain) *(ICMI '11)*. Association for Computing Machinery, New York, NY, USA, 263–270. https://doi.org/10.1145/2070481.2070530

[3] R. Ballagas, J. Borchers, M. Rohs, and J. G. Sheridan. 2006. The smart phone: a ubiquitous input device. *IEEE Pervasive Computing* 5, 1 (2006), 70–77.

[4] Sebastian Boring, Dominikus Baur, Andreas Butz, Sean Gustafson, and Patrick Baudisch. 2010. Touch projector: mobile interaction through video. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2287–2296.

[5] Amira Bouabid, Sophie Lepreux, Christophe Kolski, and Clémentine Havrez. 2014. Context-sensitive and Collaborative application for Distributed User Interfaces on tabletops. In *Proceedings of the 2014 Workshop on Distributed User Interfaces and Multimodal Interaction*. ACM, 23–26.

[6] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (Jan. 2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[7] Frederik Brudy, Christian Holz, Roman Rädle, Chi-Jui Wu, Steven Houben, Clemens Nylandsted Klokmose, and Nicolai Marquardt. 2019. Cross-Device Taxonomy: Survey, Opportunities and Challenges of Interactions Spanning Across Multiple Devices. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, 562:1–562:38. https://doi.org/10.1145/3290605.3300792

[8] Xiang "Anthony" Chen, Tovi Grossman, Daniel J. Wigdor, and George Fitzmaurice. 2014. Duet: Exploring Joint Interactions on a Smart Phone and a Smart Watch. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 159–168. https://doi.org/10.1145/2556288.2556955

[9] Ming Ki Chong and Hans W. Gellersen. 2013. How Groups of Users Associate Wireless Devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 1559–1568. https://doi.org/10.1145/2470654.2466207

[10] Pierre Dillenbourg. 2013. Design for classroom orchestration. *Computers & Education* 69 (Nov. 2013), 485–492. https://doi.org/10.1016/j.compedu.2013.04.013

[11] Pierre Dillenbourg, Sina Shahmoradi, and Jennifer K Olsen. 2019. Opening the Doors of Classrooms for Technologies: Measures for Orchestrability. *DEStech Transactions on Social Science, Education and Human Science* ICEdDE (2019).

[12] P. Dillenbourg and P. Tchounikine. 2007. Flexibility in macro-scripts for computer-supported collaborative learning: Flexibility in macro-scripts for CSCL. *Journal of Computer Assisted Learning* 23, 1 (Jan. 2007), 1–13. https://doi.org/10.1111/j.1365-2729.2007.00191.x

[13] Pierre Dillenbourg, Guillaume Zufferey, Hamed Seyed Alavi, Patrick Jermann, Lenh Hung Son Do, Quentin Bonnard, Sébastien Cuendet, and Frédéric Kaplan. 2011. Classroom orchestration : The third circle of usability. In *Connecting Computer-Supported Collaborative Learning to Policy and Practice: CSCL2011 Conference Proceedings. Volume I — Long Papers*, Vol. 1. International Society of the Learning Sciences, Hong Kong, China, 510–517.

[14] Son Do-Lenh, Patrick Jermann, Amanda Legge, Guillaume Zufferey, and Pierre Dillenbourg. 2012. TinkerLamp 2.0: Designing and Evaluating Orchestration Technologies for the Classroom. In *21st Century Learning for 21st Century Skills*, Andrew Ravenscroft, Stefanie Lindstaedt, Carlos Delgado Kloos, and Davinia Hernández-Leo (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 65–78.

[15] Louis Faucon, Jennifer K Olsen, Stian Haklev, and Pierre Dillenbourg. 2020. Real-Time Prediction of Students' Activity Progress and Completion Rates. *Journal of Learning Analytics* 7, 2 (2020), 18–44.

[16] Frank Fischer and Pierre Dillenbourg. 2006. Challenges of orchestrating computer-supported collaborative learning. In *87th AERA*.

[17] Aakar Gupta, Thomas Pietrzak, Cleon Yau, Nicolas Roussel, and Ravin Balakrishnan. 2017. Summon and Select: Rapid Interaction with Interface Controls in Mid-Air. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces* (Brighton, United Kingdom) *(ISS '17)*. Association for Computing Machinery, New York, NY, USA, 52–61. https://doi.org/10.1145/3132272.3134120

[18] Stian Haklev, Louis Pierre Faucon, Thanasis Hadzilacos, and Pierre Dillenbourg. 2017. FROG: rapid prototyping of collaborative learning scenarios. In *EC-TEL Demos*.

[19] Doris Hausen, Aurélien Tabard, Attila Von Thermann, Kerstin Holzner, and Andreas Butz. 2014. Evaluating peripheral interaction. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction*. 21–28.

[20] Kenneth Holstein, Bruce M McLaren, and Vincent Aleven. 2017. Intelligent tutors as teachers' aides: exploring teacher needs for real-time analytics in blended classrooms. In *Proceedings of the seventh international learning analytics & knowledge conference*. 257–266.

[21] Kenneth Holstein, Bruce M McLaren, and Vincent Aleven. 2019. Designing for complementarity: teacher and student needs for orchestration support in AI-enhanced classrooms. In *International Conference on Artificial Intelligence in Education*. Springer, 157–171.

[22] Steven Houben and Nicolai Marquardt. 2015. WatchConnect: A Toolkit for Prototyping Smartwatch-Centric Cross-Device Applications. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. ACM, New York, NY, USA, 1247–1256. https://doi.org/10.1145/2702123.2702215

[23] Steven Houben, Søren Nielsen, Morten Esbensen, and Jakob E. Bardram. 2013. NooSphere: an activity-centric infrastructure for distributed interaction. In *Proceedings of the 12th International Conference on Mobile and Ubiquitous Multimedia - MUM '13*. ACM Press, Lulea;, Sweden, 1–10. https://doi.org/10.1145/2541831.2541856

[24] Steven Houben, Paolo Tell, and Jakob E Bardram. 2014. Activityspace: Managing device ecologies in an activity-centric configuration space. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*. 119–128.

[25] Shahram Izadi, Harry Brignull, Tom Rodden, Yvonne Rogers, and Mia Underwood. 2003. Dynamo: a public interactive surface supporting the cooperative sharing and exchange of media. In *Proceedings of the 16th annual ACM symposium on User interface software and technology*. 159–168.

[26] Ghita Jalal, Valentin Lachand, Aurélien Tabard, and Christine Michel. 2018. How Teachers Prepare for the Unexpected Bright Spots and Breakdowns in Enacting Pedagogical Plans in Class. In *Lifelong Technology-Enhanced Learning (Lecture Notes in Computer Science)*. Springer, 59–73.

[27] Wendy Ju and Larry Leifer. 2008. The design of implicit interactions: Making interactive systems less obnoxious. *Design Issues* 24, 3 (2008), 72–84.

[28] Ahmed Kharrufa, James Nicholson, Paul Dunphy, Steve Hodges, Pam Briggs, and Patrick Olivier. 2015. Using IMUs to Identify Supervisors on Touch Devices. In *Human-Computer Interaction – INTERACT 2015 (Lecture Notes in Computer Science)*, Julio Abascal, Simone Barbosa, Mirko Fetter, Tom Gross, Philippe Palanque, and Marco Winckler (Eds.). Springer International Publishing, 565–583.

[29] Stefan Kreitmayer, Yvonne Rogers, Robin Laney, and Stephen Peake. 2013. UniPad: orchestrating collaborative activities through shared tablets and an integrated wall display. In *Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing - UbiComp '13*. ACM Press, Zurich, Switzerland, 801. https://doi.org/10.1145/2493432.2493506

[30] Valentin Lachand, Christine Michel, and Aurélien Tabard. 2019. Toccata: Supporting Classroom Orchestration with Activity Based Computing. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 2, Article 53 (June 2019), 24 pages. https://doi.org/10.1145/3328924

[31] Can Liu, Olivier Chapuis, Michel Beaudouin-Lafon, and Eric Lecolinet. 2017. CoReach: Cooperative Gestures for Data Manipulation on Wall-Sized Displays. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 6730–6741. https://doi.org/10.1145/3025453.3025594

[32] Chee-Kit Looi and Yanjie Song. 2013. Orchestration in a networked classroom: Where the teacher's real-time enactment matters. *Computers & Education* 69 (Nov. 2013), 510–513. https://doi.org/10.1016/j.compedu.2013.04.005

[33] Mateus M Luna, Thyago P Carvalho, Fabrizzio Alphonsus AMN Soares, Hugo AD Nascimento, and Ronaldo M Costa. 2017. Wrist Player: a smartwatch gesture controller for smart TVs. In *2017 IEEE 41st Annual Computer Software and Applications Conference (COMPSAC)*, Vol. 2. IEEE, 336–341.

[34] Leilah Lyons, Joseph Lee, Christopher Quintana, and Elliot Soloway. [n.d.]. MUSHI: A Multi-Device Framework for Collaborative Inquiry Learning.

[35] de la prospective et de la performance Ministère de l'éducation nationale. Direction de l'évaluation. 2019. *Repères et références statistiques: sur les enseignements, la formation et la recherche*. OCLC: 1130086913.

[36] Meredith Ringel Morris. 2012. Web on the Wall: Insights from a Multimodal Interaction Elicitation Study. In *Proceedings of Interactive Tabletops and Surfaces* (proceedings of interactive tabletops and surfaces ed.). ACM. https://www.microsoft.com/en-us/research/publication/web-on-the-wall-insights-from-a-multimodal-interaction-elicitation-study/

[37] Meredith Ringel Morris, Andreea Danielescu, Steven Drucker, Danyel Fisher, Bongshin Lee, m. c. schraefel, and Jacob O. Wobbrock. 2014. Reducing Legacy Bias in Gesture Elicitation Studies. *interactions* 21, 3 (May 2014), 40–45. https://doi.org/10.1145/2591689

[38] Meredith Ringel Morris, Anqi Huang, Andreas Paepcke, and Terry Winograd. 2006. Cooperative Gestures: Multi-User Gestural Interactions for Co-Located Groupware. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Montréal, Québec, Canada) *(CHI '06)*. Association for Computing Machinery, New York, NY, USA, 1201–1210. https://doi.org/10.1145/1124772.1124952

[39] Miguel A Nacenta, Samer Sallam, Bernard Champoux, Sriram Subramanian, and Carl Gutwin. 2006. Perspective cursor: perspective-based interaction for multi-display environments. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*. 289–298.

[40] Jennifer K Olsen, Nikol Rummel, and Vincent Aleven. 2021. Designing for the co-orchestration of social transitions between individual, small-group and whole-class learning in the classroom. *International Journal of Artificial Intelligence in Education* 31, 1 (2021), 24–56.

[41] Luis P. Prieto, Martina Holenko Dlab, Israel Gutié, N.A. rrez, Mahmoud Abdulwahed, and Walid Balid. 2011. Orchestrating technology enhanced learning: a literature review and a conceptual framework. *International Journal of Technology Enhanced Learning* 3, 6 (2011), 583. https://doi.org/10.1504/IJTEL.2011.045449

[42] Gonzalo Ramos, Kenneth Hinckley, Andy Wilson, and Raman Sarin. 2009. Synchronous Gestures in Multi-Display Environments. *Human–Computer Interaction* 24, 1-2 (2009), 117–169. https://doi.org/10.1080/07370020902739288

[43] Jun Rekimoto. 1997. Pick-and-drop: a direct manipulation technique for multiple computer environments. In *Proceedings of the 10th annual ACM symposium on User interface software and technology - UIST '97*. ACM Press, Banff, Alberta, Canada, 31–39. https://doi.org/10.1145/263407.263505

[44] María Jesús Rodríguez-Triana, Alejandra Martínez-Monés, Juan I. Asensio-Pérez, and Yannis Dimitriadis. 2015. Scripting and monitoring meet each other: Aligning learning analytics and learning design to support teachers in orchestrating CSCL situations. *British Journal of Educational Technology* 46, 2 (2015), 330–343. https://doi.org/10.1111/bjet.12198 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/bjet.12198

[45] Jeremy Roschelle, Yannis Dimitriadis, and Ulrich Hoppe. 2013. Classroom orchestration: Synthesis. *Computers & Education* 69 (Nov. 2013), 523–526. https://doi.org/10.1016/j.compedu.2013.04.010

[46] Dennis Schneider, Julian Seifert, and Enrico Rukzio. 2012. Mobies: extending mobile interfaces using external screens. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*. 1–2.

[47] Alemayehu Seyed. 2013. *Examining User Experience in Multi-Display Environments*. Ph.D. Dissertation. University of Calgary.

[48] Mike Sharples. 2013. Shared orchestration within and beyond the classroom. *Computers & Education* 69 (Nov. 2013), 504–506. https://doi.org/10.1016/j.compedu.2013.04.014

[49] Léo Sicard, Aurélien Tabard, Juan David Hincapié-Ramos, and Jakob E Bardram. 2013. Tide: Lightweight device composition for enhancing tabletop environments with smartphone applications. In *IFIP Conference on Human-Computer Interaction*. Springer, 177–194.

[50] Pierre Tchounikine. 2013. Clarifying design for orchestration: Orchestration and orchestrable technology, scripting and conducting. *Computers & Education* 69 (Nov. 2013), 500–503. https://doi.org/10.1016/j.compedu.2013.04.006

[51] Radu-Daniel Vatavu and Jacob O. Wobbrock. 2015. Formalizing Agreement Analysis for Elicitation Studies: New Measures, Significance Test, and Toolkit. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. ACM, New York, NY, USA, 1325–1334. https://doi.org/10.1145/2702123.2702223

[52] Pedro G. Villanueva, Ricardo Tesoriero, and Jose A. Gallud. 2014. Performance Evaluation of Proxywork. In *Proceedings of the 2014 Workshop on Distributed User Interfaces and Multimodal Interaction* (Toulouse, France) *(DUI '14)*. ACM, New York, NY, USA, 42–45. https://doi.org/10.1145/2677356.2677665

[53] John Watson. 2008. Blended Learning: The Convergence of Online and Face-to-Face Education. Promising Practices in Online Learning. *North American Council for Online Learning* (2008).

[54] Jacob Wobbrock, Meredith Ringel Morris, and Andy Wilson. 2009. User-Defined Gestures for Surface Computing. In *CHI '09 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (chi '09 proceedings of the sigchi conference on human factors in computing systems ed.). ACM, 1083–1092. https://www.microsoft.com/en-us/research/publication/user-defined-gestures-for-surface-computing/

[55] Jacob O. Wobbrock, Htet Htet Aung, Brandon Rothrock, and Brad A. Myers. 2005. Maximizing the Guessability of Symbolic Input. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems* (Portland, OR, USA) *(CHI EA '05)*. ACM, New York, NY, USA, 1869–1872. https://doi.org/10.1145/1056808.1057043

[56] Marisol Wong-Villacres, Margarita Ortiz, Vanessa Echeverría, and Katherine Chiluiza. 2015. A Tabletop System to Promote Argumentation in Computer Science Students. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces* (Madeira, Portugal) *(ITS '15)*. ACM, New York, NY, USA, 325–330. https://doi.org/10.1145/2817721.2823501