Collaborative Design-in-use: an Instrumental Genesis Lens in Multi-device Environments

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The fast-growing proliferation of multi-device systems has been reshaping the contexts in which collaborative activity takes place. The evolving materialisation of multi-device environments (MDEs) is likely to have an impact on foundational CSCW research, in ways that go beyond studying cross-device interaction. Designers, developers and researchers are reporting emerging challenges in understanding, supporting and designing for complex collaborative activity in MDEs. We argue that the theoretical perspective of Instrumental Genesis can help unveil the complex, dynamic relationships between design, people, tools, tasks and activities in technology-rich MDEs. In this paper, we use extracts from our research on collaborative work in an MDE to illustrate how ideas from the theory of Instrumental Genesis can help reveal important aspects of change and stability. We show how collaborative *design-in-use* contributes to the joint evolution of MDEs and the working practices unfolding within them.

CCS Concepts: • **Information systems → Collaborative and social computing systems and tools** • **Human-centered computing → Collaborative interaction**

KEYWORDS

Instrumental Genesis; multi-device; collaboration; collocated; design; appropriation; MDE; multitouch

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1 INTRODUCTION

There is a rapidly growing proliferation of technology-rich, multi-user, multi-device environments (MDEs) [1]. The use of an ecology of devices, such as large multitouch screens, handheld devices (e.g. tablets and smartphones), tangible user interfaces and other mainstream personal devices (e.g. laptops, digital pens and pointing devices) is becoming more common in a range of professional areas such as crisis management (e.g. [16]), operations control (e.g. [10]), business modelling (e.g. [43]), classroom learning (e.g. [32]), and simulation training (e.g. [40, 68]). Neither the concept nor the materialisation of MDEs are new [31, 58, 59]. However, a recent literature review [69] found that CSCW research has largely remained focused on designing and evaluating single-device interactions: less than 20% of CSCW design and evaluation work over the last 25 years has involved the use of multiple devices. There is a growing body of HCI research exploring user interface issues in terms of cross-device interaction (see recent examples in [26, 27, 45, 47]). Nonetheless, not much is known about how these actually affect group collaboration

[26]. In addition, these interaction techniques are usually tested under controlled lab conditions, rather than in more realistic, open-ended scenarios [44].

The proliferation of MDEs can have important implications for foundational CSCW research, as highlighted by Wallace et al. [69]. This is because a growing ecological approach goes beyond cross-device interaction to include, for example, awareness and reflection during collaborative work (e.g. see recent work in [63]); the analysis of effective productive teamwork (e.g. [39]); and the design and adoption of new tools and techniques based on users' previous experiences with tools in authentic contexts (e.g. [44]). However, designers, developers and researchers are reporting new challenges in understanding, supporting and designing for the complexity of collaborative activity in multi-user MDEs (see recent review and analysis papers in [22, 39, 49, 72]). In these emerging environments, people typically collaborate through a mix of face-to-face and technology-mediated interactions, using multiple channels for communication, and various digital and non-digital artefacts. It is common for each individual to participate in these collaborative exchanges from a particular position or role within a group, exhibiting their unique user experience, according to their digital literacy skills, previous device-usage experience, domain expertise, etc. In successful collaborations, group members will often develop their own interaction styles, forms of communication, work practices, strategies, values, etc. Many of these will be mediated through artefacts. Thus, it is important that the design of a multi-user MDE accounts for the ways artefacts mediate people's interactions. In short, designing for collaborative group work entails dealing with high degrees of *complexity* and *uncertainty*, which turn out to be particularly critical in collocated multi-device physical spaces. These complexities and uncertainties certainly need to be considered in terms of interface interaction but also in light of how the *social* and *epistemic* aspects of joint work evolve over time [38].

The theoretical perspective of Instrumental Genesis (IG) [21, 52, 67] aims at explaining how activity is mediated by *mentally* constructed *instruments* over time. According to IG, *instruments* mediate people's activity with artefacts, with other users and with themselves. Although there is a well-established foundational body of work in CHI and CSCW pointing at the relationship between design and use of artefacts (e.g. [2, 61, 71]), IG offers a lens to explain this relationship, by explicitly foregrounding the continuation of *design-in-use* as an evolutionary process not only of the digital systems, but also of people and their practices [51]. On the one hand, people often 'change' the originally intended design of an artefact while *in-use*, to better accommodate their needs [20, 41]. On the other hand, individual and group practices also evolve. These practices may be passed on to others: communicated (implicitly or explicitly) to other people, who may then develop their own usage practices [21].

We argue that Instrumental Genesis can be applied as a framework for understanding the complex relationship between tools, tasks and people, through their emergent activity in multi-user, multi-device environments. In this sense, our work aims at contributing with an approach to collaborative design-in-use that acknowledges its evolutionary nature – the systemic Instrumental Genesis lens provides the basis for explaining collaborative activity through a focus on what collaborators actually do, in multi-device environments.

The rest of the paper is structured as follows. The next section provides a brief literature review describing the theoretical foundations underpinning IG, its relevance to CSCW and some of the similarities and differences between IG and other theoretical approaches. Section 3 presents the MDE in which we observed complex collaborative activity. Section 4 presents our findings, through examination of three vignettes that illustrate how a systemic IG lens contributes to explaining complex relationships between people, tools, tasks and activities in MDEs. We conclude the paper by articulating some of the key strengths and weaknesses of IG as highlighted in our empirical work. We also discuss broader implications for using this approach to understand complex multi-user, multi-device activity, as well as for further research in HCI and CSCW.

2 BACKGROUND

2.1 Instrumental Genesis in Multi-device Environments

2.1.1 What is Instrumental Genesis? In a nutshell, Instrumental Genesis explains how an actor (or actors) progressively constructs the use of artefacts, tools, devices, resources etc., for a particular purpose in a specific context [50]. Instrumental Genesis (IG) takes seriously the *situated* nature of people's actions [52]. Human interaction with the world is understood as multi-dimensionally mediated by artefacts, as users need to manage and maintain coherence across software, devices, information structures, tasks, etc [5, 28]. In this view, unexpected or novel uses of a device – relative to the functions intended by the designers – are not necessarily indicative of a 'usability problem' or 'design shortcomings', but rather can be seen as the user's contribution to the development of such a device [4, 21]. In line with the concept of appropriation of interactive technologies [15], IG considers *design* decisions as intentions, proposals or invitations to the users and it is up to them to reshape or reconfigure the instruments that mediate their activity. Both *design* and *use* are thus constitutive of the design process [3, 21], where *design* (what designers intend would be 'expected use') can be called *design-for-use* and the actual *use* (what users do with the design intentions materialised in an object, artefact, tool, device etc.) can be referred to as *design-in-use* [21].

Central concepts in IG are those of 'instrument', 'instrumentalisation', 'instrumentation' and 'instrument-mediated activity' [67]. An *instrument* is a functional unit that has two components. The first component is the material or technical artefact (e.g. the tool or device). This can be part of an artefact, a whole artefact or a group of artefacts. The second (psychological) component is associated with the cognitive structure into which the users' past experiences are organised and which can be drawn upon by them in a particular situation. These two components are usually called the *artefact* and the *utilisation* scheme (the latter based on Piaget's notion of scheme [48]) respectively [4]. An instrument gets progressively constructed through two processes. The first of these, *instrumentalisation,* refers to the evolution or adjustment of the artefact itself, e.g. by transforming one or more of its physical characteristics. This adjustment may be temporary or may result in permanent changes in the artefact [4]. The second process, *instrumentation*, refers to the evolution of the utilisation scheme. In other words, the evolving nature of a subject's ability to apply or use a tool [28]. Although these processes can co-occur and equally contribute to the development of the instrument, it is often the case that the processes alternate in prominence [4]. The original IG theoretical perspective indicates that these Instrumental Genesis processes occur both individually and collectively: "*instruments will thus appear as both private and social entities resulting from their history, used both individually and collectively and shared among work groups and trade communities*" ([52], p. 2). For IG, the unit of analysis is the actual *instrument-mediated activity,* as this keeps in focus the characteristics of individuals (subjects), their aims (objects), relationships, the cultural tools and the context; and the main purpose of analysis is to trace the genesis of such instruments. The genesis of instruments is thus distributed between designers and users [50] and socially constructed by users as a collective [66].

At least four types of mediation have been identified in IG [52]. Two of these are oriented towards the objects: epistemic and pragmatic. The first concerns coming to understand the object and the second involves action on the object. The other two types of mediation are oriented towards the acting subjects: *interpersonal* and *reflexive/heuristic. Interpersonal mediation* involves understanding others and/or performing an action on or with them. *Reflexive/heuristic* mediation is about the subject's control of their own activity, based on progress and problems arising [4]. An artefact may embody design intentions related to serving as a mediator of more than one type, or users can appropriate the artefact for multiple types of mediation. This is called *multimediation.* Often, multiple tools or devices (artefacts in general) are available in the same work space, each offering opportunities for mediating activity. Group situations entail a process of negotiation of

meaning and use of artefacts, since many instruments per individual can be generated [66]. As these instruments are not generated in isolation, the concept of *instrument system* organises instruments of heterogeneous nature into a more homogenous system [52]. This concept is critical for understating IG in MDEs, as we will show later in the paper.

As depicted in Figure 1, the MDE can play a central mediating role between designers of the MDE, the individuals that form part of a group (the subjects), and the CSCW task these aim to accomplish or the objects they need to build or interact with. In design-time (*design-for-use*), the designers of the MDE materialise their design intentions by creating or putting together the different components of the MDE (see arrow between nodes *Designer* and *MDE* in Figure 1). They can also directly interact with users (see arrow between nodes *Designer* and *Subjects*) to elicit design requirements or to co-design the system with them (e.g. through participatory approaches [56]). In use-time (*design-for-use*), users can certainly interact directly with the object of the activity (see arrow between nodes: Users and CSCW task; *Subject-Object*) if they do not make use of any of the elements of the MDE. Most likely, the MDE would emerge as an instrument system while group members create objects or perform tasks within and through the different elements of the MDE (*Subject-MDE-Object*). In doing so, the dual process of *instrumentalisation* and *instrumentation* can unfold for each group member and for each element or group of elements within the MDE. This also means that there exists an implicit channel of interaction between designers and users (*Designer-MDE-Subject*) where the MDE becomes a multi-mediator of such activity (*Designer-MDE-Object*). The design intentions are appropriated by the users and, sometimes, reconfigured in use-time, thus leading to *design-for-use*.

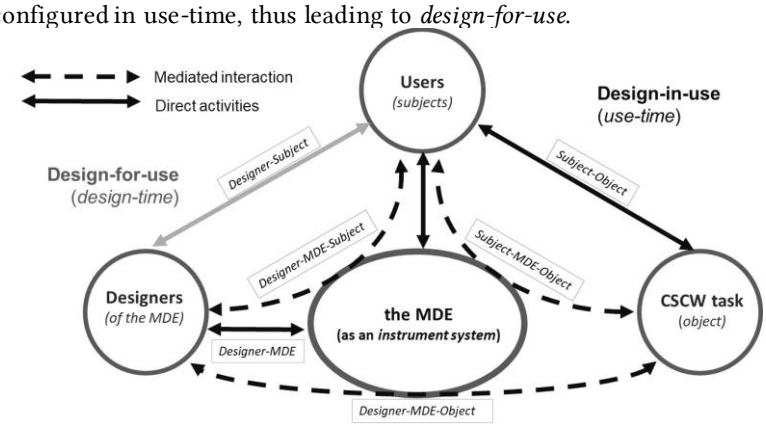

Figure 1. Instrumental mediation of a multi-user multi-device environment inspired on [52, 70].

Lonchamp [34], Folcher [21] and Rabardel and Samurçay [53] broadened the dimensions of mediating artefacts by associating them with two main kinds of activities in which users can be intentionally engaged: *productive* and *constructive*. *Productive activities* are directly associated with achieving the goals and aims, or perform actions to produce *visible* outcomes for a given task. By contrast, *constructive activities* are commonly concerned with elaborating resources that may be used to facilitate the achievement of such tasks. These activities are closely related, and so failures in productive activities may lead to adaptations and development of constructive activities [21]. Social practices commonly involve both productive and constructive activities intertwined in different proportions [17].

2.1.2 Why is Instrumental Genesis relevant for CSCW? Instrumental Genesis is particularly focused on explaining some relationships between *design* and *use* in people's mediated activity with artefacts. However, there is still a lack of research applying this perspective to explore the complexity of *many-to-many* relationships involving people and devices in MDEs. Examples in

the IG literature have tended to focus on either *single-user* interactions or *multiple-users* interacting with one object. Some of the original examples to illustrate IG included objects such as a mechanic's workbench [52] and a calculator [65]. Other IG-related works covered social aspects and the analysis of instrument systems, illustrated through individuals collaborating around a single artefact. Examples of these '*multi-user*' artefacts are varied in form and degree of complexity, from a non-digital scheduling grid [52] or a calendar app [5] to a knowledge-sharing database [21] or collaborative online systems [8, 46]. By contrast, other work has explored how individuals interact with collections of artefacts mediated by instrument systems. Examples include virtual multi-tool environments (e.g. [34, 46]) or arrays of systems used in organisational environments (e.g. [4, 21]). There is very little research on the use of the IG lens to understand *many-to-many* relationships in collocated spaces, such as we find with multi-user MDEs. Interestingly, IG has attracted the attention of several researchers in the area of computer-supported collaborative learning (CSCL) [9, 13, 34, 46, 54]. Some of these have taken an ecological stance in studying multi-user (student and/or teacher) activity, mediated by online learning systems (e.g. see recent example in the area of mobile learning in [9]).

Kaptelinin and Bannon [30] have argued for a stronger focus in HCI research on developing concepts and methods to support design and analysis through an understanding of habitats and ecologies, rather than merely concentrating on the design of more advanced technological artefacts. In this sense, there is a great potential for CSCW *designers* to take a holistic IG perspective to understand the evolving appropriation of the digital and non-digital elements in increasingly complex MDEs. Ideally, designers would create flexible open systems which could be efficiently transformed into instruments in practice [28]. IG may be helpful for *developers* and *researchers* to move forward, going beyond findings from studies of specific technologies, to a more integrated perspective that acknowledges how design can shape the ways people interact with and through *assemblies of physical and digital resources*, and how *in-use* interactions can also re-shape the design. IG is not restricted to understanding technological aspects, but also underlines the importance of tasks, spaces, social constructs, etc. So this approach can also sensitise (design) *ethnographers* – offering new lenses to frame their analyses of the integration of the physical, social and virtual realms [5, 30].

2.2 Related Work

Instrumental Genesis (IG) builds on activity theory (AT) [33, 42] and situated cognition [7]. IG authors explicitly emphasise its dialectical, anthropocentric and psychological nature [4], focusing on the genesis of instruments (partly psychological constructs, partly artefacts) [62], where design is seen as an evolutionary process, working at various levels (human and technological) and involving multiple sets of actors (e.g. both designers and users). IG is different from other widely known theoretical approaches such as distributed cognition (DCog) [25], situated action [60], and AT itself, since its aim is not to just provide a framework to help an analyst match their data to certain concepts, but rather to make stronger links between low level actions *in-use* and design (*for-use*) and the different sets of people who are involved in design.

Engeström's extension of activity theory [19] has been influential in CSCW. It added critical concepts related to group work in terms of epistemic and social constructs (e.g., divisions of labour, community, rules). A number of approaches and frameworks were proposed following this AT extension. These included Realist Activity Theory in the context of digital libraries [57], the Activity Space framework for collaborative learning [23], and the application of AT in document/knowledge management [11]. Although IG is *not* an extension of AT *per se*, these related works engage in similar endeavours aimed at understanding CSCW mediated activity.

Yvonne Rogers [55] thoroughly discussed the role of theories in HCI, their relevance and their unique development in CSCW. One criticism is that most theories derive from lab studies, generating high-level constructs that are not easily mapped into the messy human-computer

interactions in the real world ([55] p. 13). Rogers [42] has also pointed out that, although the terms and concepts proposed in AT extensions may help the analyst to recognise problems in peoples' activity, one critical shortcoming is the expertise required to *see* how multiple AT elements emerge from group activity. Halverson [24] has added that theories commonly used in CSCW, such as AT and DCog, have been useful to describe the world using a common vocabulary for comparison, but they do not offer a direct route to aid design or derive system requirements. This has motivated some researchers and designers to move away from such theoretical models and towards pragmatic/cultural-historical approaches, focused on experience [6].

We suggest that bringing an IG lens to CSCW is not about finding a theoretical perspective to explain everything in CSCW nor to help an analyst match AT concepts to their data. Quite the opposite, the value and potential power of IG is in foregrounding design aspects of CSCW activity by providing a lens that can explain how a group is engaged in individual, collaborative and social appropriation of instruments, and how these instruments can serve to explain how people and artefacts (including devices) co-evolve in both design time (*design-for-use)* and in use time (*design-in-use*). Thus, IG has a strong focus on design [67] and the micro-genetics of mediated activity [62]. This latter refers to how the genesis of instruments can be directly observable from low level interactions. In this way, IG can also rely on 'thick' descriptions to explain activity (like AT, DCog, ethnomethodology, etc) but the unit of analysis is focused on the genesis of psycho-material instruments, which are directly tied to evolutionary design implications in terms of: the original design intentions of the 'designers'; the appropriation of these by the users; the potential further development of such intentions *in-use*; and the potential re-design of material aspects of the technology by the 'designers' as a result of such *use*. In fact, as we will show later, we performed a form of conversation analysis in our study using IG as a lens to find evidence that suggested micro-genetics in instrument mediated CSCW activity.

Another particular characteristic of Instrumental Genesis is that it explains why users should not be considered as fixed, interchangeable entities, but rather as acting subjects who evolve through interactions with tools and other people, who are themselves also evolving [62]. IG also helps distinguish two sets of people involved in the CSCW design process. One of these sets includes people who have an acknowledged status as designers (the people involved in *design-for* others' use). This set creates opportunities for use, observes how activity unfolds *in-use* and follows up with more permanent adjustments to the tools (etc.) that they have designed. The second set are the users, who also design as and when they use the tools (etc.). The users appropriate the design intentions via instruments, generated *in use*. Lastly, IG is intended to be directly applied *in-use*, in-the-wild, where the unpredictable can and often does happen.

Kaptelinin [28] suggested that the implications of IG for design are both theoretical and practical. Instead of being aimed at generalising findings, IG is focused on explaining why some things work (or do not work) for some users in some situations. Kaptelinin [28] and Tamborg [62] have discussed theoretical aspects of IG in relation to other theoretical perspectives in HCI. Tchounikine [64] recently performed a comprehensive analysis and reviewed significant differences and overlaps between IG and other theoretical and applied approaches within HCI, CSCW and Engineering (e.g. AT, genres and organisational theory, semiotic engineering, and design methodologies). Tchounikine concluded that designing for instrument-mediated activity "*should be considered a primary goal of any design method*" ([15, 64] p. 198). Tchounikine describes software appropriation as a process by which technology is adapted in practice. He notes that users have agency to adapt their behaviours in response to the technology, and likewise, users also adapt the technology according to their needs. He warns us that designing for software appropriation is complex, as it is impossible "*to fully predict how users will appropriate software*" (p.158). The development of instruments involves psychological and social factors, but also the dynamic nature of the instruments themselves. Thus, design is about "*creating the conditions*" and

having a "*strategy for offering users the means to resolve tensions between instruments and artefacts themselves*" (p.158). Similar to our study, this conceptualisation of designing for appropriation highlights users as continuing "*software design in use*".

However, Tchounikine situates his discussion through examples of teacher's use of a scenario editor, where individual teachers use a system to adapt a learning scenario to their view and teaching context. He explains that teachers are likely to have developed particular expertise or idiosyncratic practices, which influence their own perspectives and interactions. Tchounikine's scenario is, nevertheless, different from our own context. Our scenario involves a group of educational designers using multiple devices to create learning tasks. Each of these designers would bring their own particular expertise and idiosyncratic practices, not only related to each of the devices available in the MDE, but also to the particular mix of devices in the room. In addition, each designer would bring their own pedagogical beliefs and assumptions about how people learn. Similar to Tchounikine's example, our context implies a modification in the cluster of instruments by these designers. But our context involved a task tackled by a team, where designers had to exchange their individual perspectives, and find a common ground for ways of dealing with multiple (and potentially varied) perceptions of the ecology of instruments.

Finally, our research aligns well with an emerging line of work in HCI by Fischer et al. [20] and Mørch et al. [41], who have been developing a similar approach to IG, starting with end-user development. Fischer developed a meta design framework and Mørch focused on the evolving nature of artefacts, which integrate technology adaptation (end-user development) and knowledge adaptation (collaborative learning).

In what follows, we turn to illustrations of each type of mediation as intended in the *design-for-use* of a MDE (Section 3) and how these were embodied as collaborative *design-in-use* during constructive and productive activities in this example MDE (Section 4).

3 DESIGN-FOR-USE: A MULTI-DEVICE STUDY

We demonstrate how the IG perspective informed our analysis of the collaborative activity of four groups of users, working in a multi-user, multi-surface environment called the Educational Design Studio (EDS). The users of the studio are themselves involved in collaborative design work: designing courses and materials for students. However, for the purposes of the current paper, when we talk about *design-for-use* we mean *our* work designing the EDS as an MDE. When we talk about *design-in-use* we are referring to how users of the EDS appropriated what we had designed for them to use in their collaborative work.

3.1 The MDE: An Educational Design Studio

The EDS (Figure 2) is a specialist design facility equipped with a range of digital and physical tools located at the University of Sydney. This multi-device space is commonly used to run different kinds of collaborative design activities of varying levels of authenticity/control and duration formats (e.g. single versus multiple sessions; partially experimental versus fully *in-the-wild* studies). The study from which we are drawing material for this paper was one of these more controlled scenarios, whose primary practical purpose was to get some insights into the collaborative activity of EDS users, while minimising the variability of the *design-for-use* intentions (tasks, roles allocation, tools configuration). This allowed us to focus on the unfolding collaborative *design-in-use* occurring in the physical space.

The tools in the EDS include large and small-sized displays which offer a range of interaction functionalities. These include a multi-touch tabletop, a multi-touch whiteboard, (3) tablets, a non-interactive dashboard, and a personal computer connected to a projector (with wireless mouse and keyboard). The space also contains a large non-digital writeable wall; paper, pencils, coloured markers, etc; and assorted furniture (table, chairs, etc). A software design tool called CoCoDes was deployed on the tabletop and the whiteboard. This tool provides a multi-touch interface

customised to support collaborative high level conceptual design work on courses for university students. Its interface offers a configurable timeline that allows educational designers to define learning tasks (e.g. lectures, modules, tutorials, group activities, etc) for students within a study period (e.g. 12 weeks). CoCoDes provides digital icons that represent each of these learning tasks, which can be manipulated by direct touch to allocate learning tasks across the timeline.

Figure 2. Illustrative MDE: the Educational Design Studio (EDS)

In sum, the tool allows groups of educational designers to configure the duration, scheduling, workflow and other characteristics of the learning tasks associated with a university course. Further details about the tool and its evaluation can be found in [36, 37]. Importantly, CoCoDes provides the functionality for participants to: i) use the tabletop as the main working device, mirroring the view on the whiteboard – or vice versa (e.g. showing and interacting with the same design in both devices), or ii) split the task so different team members can build two designs in parallel, (e.g. work on a different design in each device independently).

3.2 Participants and tasks

The study involved four teams (A, B, C and D), each of three designers (8 females and 4 males). All participants were experienced learning designers and/or teachers who were recruited from the School of Education and Social Work of the University of Sydney. Six participants from a previous study were distributed across these four teams so in each team there were 1 or 2 team members who had previously used the EDS for related purposes. Participants varied in their levels of expertise in educational design or teaching, and also in their familiarity with the devices and tools in the room. This mix of expertise and experience resembles what we commonly encounter in other more authentic design situations, conducted in the EDS.

In this study, participants were given a design problem that involved collaboratively crafting two or more educational design solutions for an existing 12-weeks course in an Engineering-related discipline. This is a kind of task that all participants were familiar with since they all had varied educational design experience. Each team was given up to 1.5 hours to generate high level educational designs. Each team member was assigned one of three possible roles (Lecturer - L, Learning Designer - LD and Quality Assurance Officer - QAO). Each participant had access to shared information about the course and its goals. Each participant also had access to specific information related to their assigned roles. The task involved enacting the roles, resolution of conflicting information, negotiation of competing goals, agreement about different versions of

the design artefacts to be created, compliance with design restrictions and the use of design patterns. All participants were given the following paper materials: a design brief (indicating the requirements and constraints of the course design), and a catalogue of pedagogical learning tasks. Each participant was also provided with a tablet device that included: digital copies of the design brief and the catalogue of tasks, and access to the university course directory, which contained detailed descriptions of previous editions of the same course.

Before engaging in the collaborative design activity, all participants completed a pre-task that consisted of a 15-20 minutes tutorial, to introduce the functionalities of the devices and other tools made available in the room. After the collaborative design activity, each participant completed an individual questionnaire about their use of the MDE. Then, a 20-minute semi-structured group debriefing (interview) was conducted with each team.

3.3 Data gathering, selection and analysis

Two researchers were present in each session in the EDS to observe the sessions and ask follow-up questions in the debriefing. Data gathering included observation notes, short individual paper questionnaires completed just after each design session, debriefing group interviews, artefacts produced (captured via digital images), and video recordings of participants' activity. These recordings were transcribed for analysis.

The unit of analysis included the groups of educational designers and the artefacts they produced as our aim was understanding subject-instrument-object triples. This type of unit of analysis builds on work by Engeström [18] and Kaptelinin [29] where the entire activity system is seen as the unit of analysis. We examined people's speech exchanges, their actions, the objects they manipulated and their interactions with and (re)design of collaborative artefacts.

Data analysis involved two researchers independently screening the video recordings of the sessions looking for moments of interest in terms of design micro-genetics. Moments of interest were selected for further analysis and each passage was thematically analysed using IG concepts, independently by both researchers. Then the researchers discussed each particular moment, selecting vignettes that could potentially point at confirming design intentions or suggesting potential re-design of the toolset. The researchers discussed their two independent analyses to reach an agreement.

In qualitative studies, notions of generalisability and reliability are usually replaced by validity and trustworthiness, rigor and attention to the quality in the research process [12]. We employed multiple qualitative techniques described in the literature as best practices for studies using such a logic of inquiry. For example, we used data triangulation (various design sessions in two studies), triangulation of sources of evidence (individual questionnaires, group interviews, artefacts, video data, observation notes), and analysis triangulation (two researchers in the analysis process). We also used thick description: a strategy in qualitative research to offer detailed information so data collection and explanations are replicable [14].

3.4 Multimediation through a collection of devices

Figure 3 presents an overview of the digital (hardware/software), non-digital, and furniture artefacts that were used by participants in the multi-device environment. For simplicity, we differentiate between *devices* (the material/physical medium) and *resources* (non-material objects that sometimes comprise the artefact). Figure 3 also summarises the intended mediating function attributed to the devices and tools in our *design-for-use* phase (epistemic, pragmatic, reflexive/heuristic and inter-personal mediations). We intended the interactive tabletop and whiteboard running the design software to facilitate pragmatic mediation. All vertical displays were intended to serve as epistemic mediators by extending the perceptual fields of the design team. The dashboard had an intended heuristic mediating role because it featured analytics about the designs being developed aimed at enhancing the teams' awareness about aspects of their

unfolding activity. The paper-based documents and the information shown on the tablet were intended to serve as epistemic mediators (e.g. as the main sources of the course and learning tasks). All tools were ultimately intended to serve as inter-personal mediators. The writeable wall, in particular, was expected to be used by teams to externalise and make their agreements explicit and visible, through recordings of action points and other annotations.

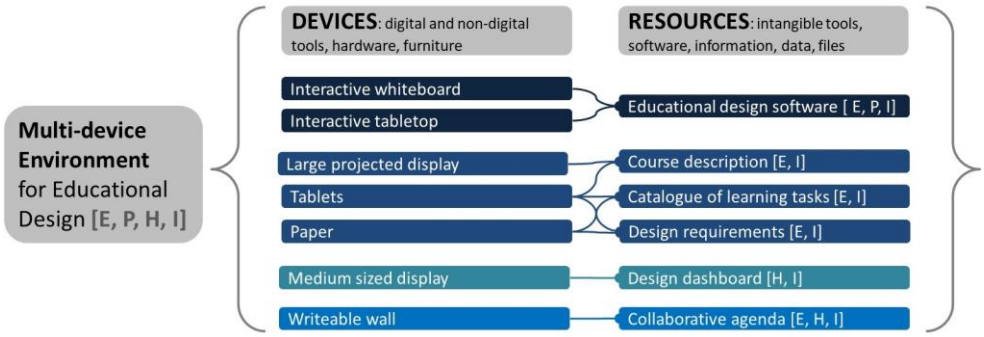

Figure 3. Devices and resources (artefacts) comprising our multi-device environment distributed at three levels: the multi-device environment as a whole, devices and intangible resources made accessible via the devices. Intended mediations associated with each are marked as follows: epistemic (E), pragmatic (P), heuristic (H) and inter-personal (I).

4 INSTRUMENTAL GENESIS IN ACTION IN THE MULTI_DEVICE ENVIRONMENT

While the previous section depicted the general *design-for-use* intentions that influenced the configuration of the multiple devices and tools in the EDS, in this section we turn to people's enactment of (or deviation from) these intentions. We focus on their interactions in the MDE, identifying both individual and collaborative *design-in-use* configurations and the genesis of multiple instruments. In particular, we discuss three vignettes (1, 2 and 3) that present evidence of Instrumental Genesis occurring at different times in the collaborative sessions, involving both productive and constructive activities; and with the arrangement of multiple devices playing a role in a distinct type of mediated and multi-mediated activity.

4.1 Vignette 1: The emergence of an instrumental system for productive design

Vignette 1
***Overview*: This vignette illustrates how epistemic decisions led to the instrumentalisation of the multi-device environment from the beginning of the activity.**
What to take away from the vignette*:** Particularly, we describe the contrast between two groups that shows how splitting the task (or not) strongly shaped the ways the interactive tabletop and the interactive whiteboard were appropriated. We illustrate the*** instrumentation process, occurring in parallel, that explained how people explored functionalities offered by some devices and why some tools were not used by some people.

Context: Our analysis of how the teams tackled the set task showed that two out of the four teams (C and D) split the task into two, working in parallel to produce their two course designs using both the interactive tabletop and the whiteboard. By contrast, the other two teams (A and B) used a different process, where all team members worked together around the same device (the interactive tabletop), building one educational design at a time. The focus of our IG analysis was on getting insights into how the teams generated an instrument (or instrument system) that could explain the configurations they performed *in-use*.

The vignette: In this example, we contrast Teams A and C. Team A's activity throughout the session consisted of the three team members standing on the same side of the interactive tabletop, working on one educational design at a time. They used the other surfaces as visual aids. By contrast, Team C followed a different dynamic. We focused on this team as their instrumentalisation process was made explicit at the beginning of the task, only 5 minutes after commencing. The following excerpt illustrates key moments after Team C reached consensus about how they would approach the task. Only the collaborator with the LD role had previous experience in the EDS. Vignette 1 illustrates the moment the team decided to split the work to then decide on the toolset and social arrangements for continuing their productive activities.

Vignette 1 (part 1): The emergence of an instrumental system for productive design	
1	L: Every course usually starts with a Lecture, let's add one.
2	LD: I better move to that side of the table so we can all see from the same side (*Figure 4-a)*
3	L: Sure, do you want to bring your chair to this side?
4	LD: (*she realises that there may not be enough space for three people working at the same side of the table*) No, it is ok, maybe I better work from my side (*as she walks back to the opposite side*).
5	L: However you feel comfortable. (*pause*) Because we are augmenting what we normally do in a course, I suggest to lay down what we normally do in a subject and then we change what we want.
6	LD: Maybe we can design one in the **tabletop** and one in the **interactive whiteboard** (*pointing at the interactive whiteboard, Figure 4-b).* We can create both as traditional designs. But we split the work and build the designs at the same time. I can do one and you both do the other.
7	L: Ah! I see what you mean. Let's do that. (*LD walks towards the interactive whiteboard, Figure 4-c*)
8	QAO: (*he adds a Lecture representation on the interactive tabletop*) Does it matter what day of the week we start?
9	L: Let's start fresh on Monday.
10	QAO: The change I did (*in the tabletop*) doesn't appear there (*in the interactive whiteboard).*
11	L: It duplicates, doesn't it? So, whatever we see here (*at the tabletop*) we see it there (*at the whiteboard*) at the same time.
12	LD: No. I selected Design B.
13	QAO: Ah, we have B there (*in the interactive whiteboard*) and here we have A

Figure 4. Vignette 1- The emergence of an instrumental system for productive design

In the first part of this vignette, team members tried to find a way to physically organise themselves around the tabletop (lines 1-4). This shows their possible attempt to instrumentalise the space (the furniture), as L agrees to work from the opposite of the table instead of having others make room for her on their side (interestingly, members of Team A didn't find problems in organising themselves at the same side of the table). In lines 5-9, members explicitly discuss how they would use the large interactive devices as *pragmatic* mediators of activity, according to their role allocation and approach to the task (social and epistemic decisions). This passage suggests what seems to be the team's shared view of the psychological component of the instrument for using both the interactive tabletop and whiteboard (collective utilisation scheme). Then, there seems to be one individual utilisation scheme per team member (lines 10-13). In this case, L did not have a clear idea of the functionality offered by the design software, but this was quickly clarified by the other two members. This dialogue illustrates the others' schemes being 'shared' with L, who seems to understand the functionality in Line 14 (see Vignette 1 part 2). The passage suggests Instrumental Genesis occurring at both individual and group levels for the coordinated use of two devices. The vignette continued as follows:

Vignette 1 (part 2): The emergence of an instrumental system for productive design	
14	L: Ah, great! Then, are you happy to work there because you have used the system before, does it bother you? We can work on the other design here. Is that ok?
15	LD: Yes, just tell me all your actions. You said we start with a Lecture on Monday.
16	L: Ok, hold on, what is the functionality to copy the first lecture into all the weeks of the semester? (*QAO presses a combination of buttons to clone the initial lecture into all weeks in the design*). Oh! There you go. Can you (*the LD*) do the same there? Ah! You did, it is copying slightly differently, but look at that! Great!
17	QAO: The **dashboard** is starting to show some information but not sure it is updated (*the dashboard updated itself with a slight delay*).
18	LD: (*all stare at the dashboard)* It doesn't matter I think. We can look at it later.
19	L: Is this also touch sensitive? (*touching at the dashboard screen, see Figure 4-d*) Ah!, no, it's not.

One of the team members (LD) had previously used the MDE to complete similar design tasks with other people, and the other two members acknowledged this, which explains why her utilisation scheme may have been more developed (as shown in line 11). L suggests that she (LD) would work alone because she may not require much help in using the interactive whiteboard. The last lines of this excerpt illustrate how, once the team discussed and agreed on the task, tools and division of work, they immediately moved onto other devices – in this case, the dashboard, which is a new tool for all team members. Although the dashboard only shows real-time statistics about the educational designs, these passages suggest how an instrument may have started to emerge for the tool, at least, at an interaction level. Line 19 is an example of this, when L refers to the utilisation scheme he has created to interact with the tabletop and the whiteboard, to test if this dashboard is also touch sensitive. After placing his five fingers and not receiving feedback, he updates his utilisation scheme and shares this with the other two team members as he says: "*Ah!, no, it's not [multitouch]*". In sum, this excerpt is a snapshot of a team's initial constructive activity where they plan how to tackle the task (which unfolded as a productive activity later).

Stepping back, and contrasting with Team A, we can also theorise about why the interactive whiteboard was not used by Team A in terms of the Instrumental Genesis process that occurred (or not) in that team. During the post-hoc interview with Team A, the member with the L role commented on her reasons for not using this device, and their focus on performing their productive activities with the tabletop only: *"With regards to the [interactive] whiteboard, which I thought I'm very comfortable with, we ended up not using it much at all, because it just wasn't purpose driven. This is really surprising for me, the whiteboard became nothing more than a projector, whereas I've utilised it in many different ways with students. Anyway, perhaps it's because the focus is not as good if compared with the interactive tabletop".* Her explanation suggests two possibilities: the utilisation scheme of this team member in using the whiteboard was generated during other activities which were quite different to the purpose of the current task. Second, a slight difference in the quality of the video display may also have had an impact on the use of the tools. If the whiteboard was available in isolation (without the tabletop), it may not have prevented using the whiteboard. This reflection illustrates the value of the Instrumental Genesis perspective in explaining why some tools are not used or are used in a way that differs from the *design-for-use* intention. It also underscores the importance of looking at the ecology of the tools as an instrument system. In relation to this argument, a member of Team C provided an insight into his evolving individual utilisation scheme, as follows: "*Although we used both, I think we could physically collaborate around the tabletop much better. Psychologically, if we're standing up over something, we dominate it, whereas with the interactive whiteboard, the device dominates us to a certain extent and by us moving forward to the tabletop, we might think... 'oh, this is me thinking pretty deeply about this', but for any person who's going up to the whiteboard, it's different because it's up and everybody's watching you do it."* (Team C, L)

In sum, Vignette 1 contrasted two groups to show how instrumentation and instrumentalisation processes were strongly influenced by the epistemic and social decisions of

the teams (e.g. deciding how to tackle the task, splitting the work and associating spaces and devices to accomplish certain sub tasks). Although designers posed some intentions in the use of the different devices, team's decisions on the way they would tackle their task can help to explain how the MDE was instrumentalised and used by each.

4.2 Vignette 2: Collective instrumentation for constructive quality assurance

Vignette 2
***Overview*: This vignette illustrates how an instrument system was collectively generated by team members to make their goals explicit and more easily assess their task using four displays at the same time.**
What to take away from the vignette: This is the only group that drew on the writeable wall. This non-digital device became critical for the constructive activities of this team. This vignette focuses on the collective instrumentation of the devices serving to track the teams' goals and the multiple representations of their team outputs. This also led to suggestions for making changes in the room (instrumentalisation).

Context: Team D had particular preferences in terms of tools usage. They used both the tabletop and whiteboard to build designs in parallel (similarly to Team C). They also used tablets and paper along with the projected display during the whole session while interacting with the larger displays. The focus in this vignette is on the way members used the writeable wall. Right from the beginning of the activity, they wrote a very detailed design agenda on the wall (see Figure 2) and they kept updating it as the session unfolded.

The vignette: This vignette focuses on the critical importance of the whitewall, a completely non-digital device, in Team D's use of the digital displays as *epistemic* and *heuristic/reflexive* mediators in the final stage of the session (that is, after more than an hour working together). The following excerpt presents key moments that illustrate how the team collectively generated an instrument system, using the devices as a whole to facilitate their own constructive process, reflection and quality assurance tracking.

Vignette 2: Collective instrumentation and instrumentalisation for constructive quality assurance using multiple devices as displays	
1	LD: (*all team members are around the tabletop*) Why don't you start checking if we include everything we agreed while I finish up this?
2	L: (*the QAO and the L walk towards the interactive whiteboard and the writeable whitewall*) Ok, for the design B we included the final group project for five weeks and group work all along the subject. This should account for 70% of the subject dedicated to groupwork (*looking at the whitewall whilst pointing at the interactive whiteboard see Figure 5-a*)
3	QAO: What does the dashboard say? Did we get there?
4	L: Yeah! 65%! It is close (*see Figure 5-b*).
	(QAO and L keep comparing their list in the whitewall with the design in the interactive whiteboard for 1 minute and then they start assessing their design in the Tabletop as follows).
5	QAO: So, it seems we have enough group work in both designs, right? (*pointing at an item on the whitewall and pointing to the tabletop for the L to double check – see Figure 5-c*)
6	L: Enough groupwork … we are forming groups from Week 2 (looking at the tabletop confused by some current changes being made my LD).
7	LD: Sorry, I am trying to put things into boxes so we can clean up the table a bit.
8	L: (*she looks at the dashboard and points at it - see Figure 5-d*) Online group work and in the lecture room, yeah! And we have the group labs. Here, 28 plus 10 is 38% of the course involves group work
9	QAO: Oh! Great! (*ticking an item in the whitewall*)

In this excerpt, LD (who is continually engaged in productive activity) suggests assessing whether their outputs were aligned with their goals (line 1). As a response (line 2), both the L and QAO immediately start using the multiple displays and the writeable wall, with their agreed agenda serving as a checklist. It seems that the three members had developed a consistent joint utilisation schema where they did not have to coordinate explicitly how they would proceed with the task. They just *knew* what they had to do. This suggests that the instrumentation

process led to the consolidation of a joint instrument for using the multiple devices (a many-to-many relation). Lines 2 to 6 show the two team members performing the quality check by looking at the whitewall, the interactive whiteboard and the dashboard (lines 2-4), then moving to assess the design at the tabletop (lines 5-9). In other words, the four displays played an important role as *epistemic* mediators during this excerpt, although they were also pragmatic or heuristic mediators at other times during the activity. The constructive and reflective process continues, with LD still performing changes at the tabletop, but showing awareness of what the others are doing (see line 7). While the tabletop was being used as an *epistemic* mediator (to know more about the status of their design output) by L and QAO, for LD the tabletop was still serving as a *pragmatic* mediator for making changes to that output.

Figure 5. Vignette 2: Instrumentation for constructive quality assurance.

The stronger focus on the psychological component of the instrument system that may have driven what appears to be a form of *design-in-use* of the MDE shown in this vignette, was further explored in the post-hoc interviews. The first insight came from the L and LD team members who described their views on their utilisation scheme for the non-digital whitewall (respectively) as follows: "*…the whitewall was my favourite to be honest. We were so focused on the structure of what we needed as we wrote on the wall and that's when we started looking at the other displays. The whitewall was key for coordinating it all" (Lecturer); and "…the wall became a window to work. This was not a computer. This was a window into our operations; I'd much rather write on a wall, than type on a document because it stays where you put it and it doesn't lag or disappear and it's shared, so you can scribble on top of someone else's stuff which you can't do in 'Word'. But it will make that go further, after that, on that board. There wasn't enough space in the wall for us by the way." (Learning Designer).* The dashboard also played a critical role in the reflection process. Both the whitewall and the dashboard were valuable as *heuristic/reflexive* mediators for the team to reflect on their own actions. This was described by the QAO as follows: "*Even from the beginning [the dashboard] helps you get a sense of what's going on. It's not just putting random things out onto the table or the whiteboard. The dashboard sits there, and it is taking account of what we design so we can easily follow up the impact of smaller actions into the larger picture."*

Adopting an IG lens to interpret the post-hoc reflections of this team helped us understand the relationship between, and impact of, the intended *design-for-use* (from multiple perspectives) on the resulting *design-in-use*. For example, LD stressed that small changes in the physical configuration of the room could have changed the dynamics of their activity, as follows: "*if there was a table over there and the whiteboard over there [both closer to each other], we would have ended up being working on one thing".* Her externalisation illustrates the scope of the utilisation scheme, as they had to create the room as a whole. However, QAO also referred to other *design-for-use* factors that influenced their work: "*We were trying to work together because we all had roles. Because 'Sally' was the Lecturer, she needed to be deciding what was going on. So, there was that sense that we were working separately at times, but we needed to kind of move along together."*

A final remark by LD sums up the key message in this vignette: Team D seems to have instrumented and instrumentalised the devices and tools in the room in coordination to track their goals. The LD even suggested small, more permanent changes as a follow up

instrumentalisation of the environment: "*I love the combination of the three [the whitewall, the interactive tabletop and whiteboard]. I have never used the interactive whiteboard for an activity like this. I still prefer the tabletop over the whiteboard, but I think it was the combination of the three that worked for us. This size of space is perfect for three people. The only thing I would move is the projected display to the left to give us more room in the wall.*"

In sum, Vignette 2 illustrated how productive and constructive activities performed by teams were mediated by the conversations prompted by the dashboard and the other displays, where the instrument system played a critical multi-mediating (epistemic, pragmatic, heuristic and inter-personal) role. Productive activities included changes performed directly on the candidate designs to "fix" or "add" the learning tasks to be proposed to learners. Constructive activities included the dialogues focused on contrasting the two candidate designs, their alignment with the agreed goals, and how they would translate in the enactment.

4.2 Vignette 3: Individual instrumentation, experience, expertise, roles and goals

Vignette 3
***Overview*: This vignette illustrates the instrumentation process at an individual level and how it is shaped by multiple factors in-use, but also related to the history of the individual.**
***What to take away from the vignette*:** A focus on distinct perspectives of the team members individually. In this vignette all team members played their roles strictly, influenced by their previous experience as teachers and learning designers. Each individual's activity was thus shaped from multiple perspectives. The vignette illustrates how the individual instrumentation is positioned within the unfolding collaborative design-in-use.

Context: While in Vignette 1, the unit of analysis was the Instrumental Genesis at a team level, in this third vignette the focus is on the instrumentation associated with one individual. This vignette is based on the activity of Team B. Like Team A, this team built two educational designs on the tabletop, one after the other. Team B used the other screens in the room, as different visual representations of the design they were building, and to get different information. Notably, LD in this team, was carrying a tablet during most of the session.

The vignette: This vignette focuses on the instrumentation process at an individual level while interacting with the devices available in the room (mostly as *epistemic* mediators). LD and QAO barely touched the interactive tabletop, leaving L to do the hands-on design work. The following excerpt captures a passage that occurred at the beginning of the session.

Vignette 3: Instrumentation based on previous experiences, social aspects and proposed tool arrangement	
1	LD: I would recommend a blended learning design for this course. Another thing I would highly recommend is to put all your lectures online. In that way you would free up time in the classroom to do Q&A sessions and practical work. [...]. (*all team members are sitting around the table, the LD looks frequently to the tablet in front of him, consulting information about the course while giving recommendations to L - Figure 6-a).*
2	L: Ok, that makes sense.
3	LD: We can try to sketch up a visual plan of the design on the **[interactive] tabletop** and then we can see how this fits into your conceptual view of the course.
4	L: Sure. But, we already have the plan from last year there in the **[vertical display]**. Why don't we check the pre-existing design before we jump into designing a whole new thing.
5	QAO: Sure, can you bring [the course directory] into the **[vertical display]**?
	(*the team keeps negotiating meaning and planning their task for 15 minutes - looking at the paper materials, LD to the tablet, and all to the vertical display controlled by L, eventually, they all move to the tabletop - Figure 6-b*)
6	LD: (*whilst L works alone at the tabletop*) why don't we have a look at the schedule [*in the vertical display*]?
7	QAO: (*interacting with the vertical display, Figure 6-c*) We have a few views here: schedule, course description; we should use this one to know what students should do. "Harry", do you prefer this view or the other one?
8	L: (*stops doing productive work at the tabletop and looks at the display*). That one is fine, so it is Week 5, we have the project, yep. (*L keeps working on the tabletop while LD and QAO keep recommending changes - Figure 6-d*)

This excerpt shows a snapshot of the instrumentation process that begins before the team moves to the area where they can interact with the devices (lines 1-5). In contrast to Team C, the

agreement on how to use the tool happens before moving to the working area. The LD and the QAO act as the drivers of the resources, making suggestions to L about the educational design activity (line 1) and how they could start working in the room (e.g. lines 3 and 5). When the team finally moves to the working area around the tabletop, LD and QAO become the 'advisors' for L to perform all the actions at the tabletop.

Figure 6. Vignette 3- Instrumentation of the instrument system based on previous experiences, social aspects and tool arrangement

The focus of analysis here is on the instrumentation process related to QAO and LD, and what motivates them to refrain from interacting with the tabletop or interactive whiteboard. It is important to note that they both had previous experience in designing courses in the EDS. By contrast, the main user in this session was the only person who had never used the tool. One *design-for-use* intention of mixing past and novice users in the teams, was for the former to lead the productive activities and for the latter to follow and provide advice to them. This group enacted quite the opposite to the initial intentions *in-use*. This mismatch between *design-for-use* and *design-in-use* was explained by the QAO after the session as follows: "*We left [L] to do all the driving on the tabletop. I didn't touch it this time and I don't think you [LD] touched it. [..] I'm reflecting now about the reason why [L] did most of the actions. It is because it makes him take more ownership about the design he is about to make. Strategically that's what I did 'take it out of your hands'*". This may explain the mismatch as a consequence of the allocation of different roles to team members. But LD added a reflection about the tools themselves: "*For me it was more about completing the task and not so much about using the tool. I think, like, last session [in the EDS] it was quite fun using the tool, it had, sort of, a novelty effect. But now I felt like the novelty effect has, sort of, worn off. It was nice seeing when [L] was doing the design, how better it flowed this time. It was nice to just let him do that, and myself just be more focused on the task*". This reflection provides a glimpse into the potentially evolving utilisation scheme of this individual by comparing his current use of the tool with a previous experience. Both reflections suggest that whilst the utilisation schemes of QAO and LD were aligned (perceiving the interactive functionality of the tabletop to be more adequately dedicated for L – the role) their individual utilisation schemes had differences. The QAO's was more oriented towards the social, whilst the LD's was more oriented towards an epistemic motivation: freedom to think about and focus on the task without worrying about the implementation.

As expected, the L reported having experienced a different challenge in terms of the utilisation scheme developed while performing the task, hinting that it was difficult for him to keep up the pace and be aware of everything at the same time. (The productive activity was left to him alone, but he also needed to keep up with the constructive conversation driven by both LD and QAO). This dilemma was described by L, in terms of multi-device interaction overload, as follows: "*In terms of the multiple faced with that [the vertical display] plus that [the interactive tabletop], plus that [the interactive whiteboard], plus that [the dashboard]; we're talking of four different user interface modalities. Some with its particular structure and a more familiar desktop windows. Jumping between the four was not easy. For a single person, at any point in time we couldn't focus and effectively use more than two.*"

Finally, LD explained his reasons for carrying a tablet during most of the activity. This was a behaviour seen among other participants, but not to the same extent. He described his motivation as follows: *"While these guys were looking at the vertical display, I was looking at the tablet because it was annoying for me to turn around all the time. But, when they were talking about, for instance, assessment, then I wanted to have my eyes on the tabletop or the display at the same time to be on the same page"*. It is possible to infer that the combination of his particular physical position and role allocation may have contributed for this participant to develop a utilisation scheme for the constant use of the tablet. First, he could mirror in the tablet what the others were looking at behind his back (through the projected display). Secondly, he constantly revised the catalogue of learning tasks, given that he strictly played his role as LD and advisor of the Lecturer. Whilst he could have used the paper version of the catalogue, an IG lens allowed us to understand more deeply the rationale behind his use of one specific tool: not particularly its usability issues, but rather the specific aspects of the situation and the emergent *design-in-use* intentions.

In sum, Vignette 3 showed how individual's utilisation schemes may co-evolve based on previous experience and task expertise but also in light of the characteristics of the current situation. Each individual's activity was thus shaped by the multiple factors, including their role and physical position in the room. The vignette illustrates how the individual instrumentation is positioned within the unfolding collaborative design-in-use.

5 DISCUSSION AND CONCLUSION

5.1 Summary

Designing for collaborative group work is challenging, for at least two reasons. First, it entails dealing with a high degree of *complexity*, which is particularly critical in collocated multi-device physical spaces, where multiple interaction modes may be possible, and each piece of hardware, software, or furniture is often infused with design intentions from different designers. Secondly, it entails a high degree of *uncertainty*, where activity is shaped by interactions with interface and tools, but are also influenced by social and epistemic components.

The theoretical perspective of Instrumental Genesis conceptualises how instruments develop over time in two ways: through the evolution of both technical and psychological properties, the artefact and the subject. In this paper, we have discussed how the application of IG can be extended to unveil the complex and unexpected relationships between people, tools, tasks and activities in MDEs. IG provides a distinctive lens for analysing and designing for CSCW activity. It frames users as engaged in continuous design *in-use* and sensitises designers to understand the critical role and scope of designing for others' use.

By making an explicit distinction between device and resource, we illustrated how the different artefacts and combination of artefacts in an MDE can be associated with particular intended functions. Analysing our three vignettes through an IG lens allowed us to identify

- how tools in the MDE can be adjusted (instrumentalisation process);
- how the ability to apply the tools to particular situations is developed by the users (instrumentation process); how team members' mental instruments evolve, depending on their previous experience in the same space;
- how instruments can be transferred from other situations, or between people who are collocated (e.g. socially appropriated);
- how design is continued in-use; why some tools or functions can be used or not; and, finally,
- how instrumental systems can be collectively generated based on multiuser interactions in the ecology of devices, but also based on individual history, context, experience, expertise, social relationships and task goals.

5.2 Limitations: what if there is no *design-in-use*?

IG focuses on *design-in-use*. So what happens with tools that are not used at all? In a recent reflection paper, Tamborg [62] questioned the extent to which IG would be helpful in situations where users deliberately do not use artefacts, due to IG's focus on how the intentions in the *design-for-use* shape or are shaped by the *design-in-use*. If a tool is not used, then the analysis refers to a situation that does not exist. In taking a systemic stance, we argue that this is not necessarily a limitation. In our study, some teams used all the tools and devices available in the design environment, while others did not use certain tools. In some of these cases, an IG lens made us wonder why some tools were used by some groups, whilst others were tried but dropped, or not even considered for the task. A limited take on IG might lead to a view that this perspective cannot explain anything about interaction if the emergent activity was not mediated by an instrument (e.g. there was not Instrumental Genesis for particular tools). The activity still unfolded, either non-mediated or mediated through "equivalent tools". However, the existence of these equally partial complementary tools in an instrument system has been recognised in IG terms as *redundancy* [52]. This seems to signal the system's robustness, since it provides flexibility during the unfolding activity in case one part of the system breaks down, but also allows for adaptation depending on the circumstances.

If we take a macro IG lens, the whole MDE can be considered as "the tool" - composed of multiple parts. In the same way the tabletop, the device, was also composed by multiple parts such as the display, the touch screen, the software application, etc. Even when a tool within the system was not used, we can still take an IG lens to analyse the functionality that was being facilitated by that device and how that functionality was not used or appropriated. In some cases, this may have occurred because the mediation happened through different artefact-instruments.

In our study, some people within our teams used either paper or a tablet for exactly the same purpose. Here, we present two explanations by two members of Teams C and D when asked about their reasons for preferring the tablet over paper to look at the same information.

"*Well, I knew that the catalogue of learning tasks was on the tablet. I first looked for it up there [in the vertical display] because I thought it was on there and I realised it wasn't and then I found it in the tablet. It's easier to scroll through a long list on the tablet than it is to carry a paper. One piece of paper is cool but a whole bunch, not so good.*" (Team C, QAO).

"Paper is very personal, whereas if you've got a tablet, it's like a communal space. It's easier to talk about something shared there. I don't know, paper doesn't work for me that way." (Team D, L).

In these two explanations, we can see that the motivation for these two participants in using the tablet was because they focused on particular tasks: navigating through a long document (epistemic mediation) and to use it as a shared device to mediate communication. We also have two distinct explanations by participants who did use the paper and rejected the idea of using a tablet:

"In the beginning when we were sitting down and talking about the task, the paper was actually quite useful because it provided us more opportunities to see and look into each other's eyes and talk about things. Instead of our focus being directed towards the tablet when we were discussing. If your focus is on a screen, you know, the zoning out may happen." (Team C, L).

"I preferred to use the paper and having all of them with me. I annotated them because that's what I do with a pen. I could have done the same thing with the tablet I guess, but to be honest I don't have one, I have one at home but I don't use it. Also, the tablet is made of delicate material and this one in particular is not mine. I needed to be careful, take care of it. Whereas the paper I could just pick it up, move ... you might notice the way I was throwing my paper around". (Team B, L).

In these two explanations we see quite different motivations for not using the tablet (e.g. lack of experience and ownership), or preferring paper as a less intrusive mediator when direct communication was more important.

In short, IG seems to be quite useful if the purpose is to look at the instrument system and the devices, tools, and parts of these are seen as functionalities of the whole system. The varied explanations point at factors related with individual task work (e.g. the need for rapid annotation, compressing information, or carrying information in the physical space), joint work (using a device to share information, or not using a device to avoid distraction), or historical implications (familiarity, previous experience). Moreover, IG does not directly address social, organisational and cultural factors, which are also likely to influence group interaction, people's choice of artefacts, etc.

Another possible limitation of IG suggested by Tamborg [62], is that IG may have worked well for the technology available when the theoretical approach was initially proposed, but it may not work so well with current technologies. Based on the vignettes we presented in this paper, we argue that this does not appear to be a valid limitation: we used current technologies that are becoming widely available in different professional environments (e.g. multiple screens, touch devices, general purpose software, multi-input devices, etc). Additionally, we also analysed how people interacted with a dashboard, which is an exemplar of a kind of interface that is becoming more common in CSCW to facilitate awareness of group processes (see recent review in [35]) and in work on information spaces (e.g. [73]). Another recent study aimed at applying IG to understand multi-mediation in mobile learning [9] also supports this idea. More work is needed to validate the applicability of IG in other multi-device contexts with multiple arrays of tools and also in those situations where data and changing visual representations may critically impact collaborative activity.

5.3 Concluding remarks

This paper has showed how an Instrumental Genesis lens can support better understanding of *design-in-use* as an evolutionary process, not only in relation to the digital systems present in multi-device environments, but also in relation to people and their practices, both individually and collectively. The potential of IG for understanding CSCW in multi-device environments is considerable. In particular, we recommend longitudinal studies aimed at understanding the sustainability of instruments and evolving practices over longer periods of activity.

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