Learning about Collaborative Design for Learning in a Multi-Surface Design Studio

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Abstract: This paper fuses research on CSCL and collaborative design for learning. Despite growing awareness in the CSCL community of the importance of design in teachers' work, there has been little empirical research on how such design is carried out, or how design for CSCL can be supported through the provision of better design tools and design methods. The paper offers an analysis of the work of four pairs of designers in our Multi-Surface Design Studio. These four dyads were completing a design task we set them, while simultaneously learning how to make good use of the various personal and shared digital tools, display surfaces and other resources in the studio. From observational and interview data, we show how collaborative design for learning needs to be understood as a complex, multiply-situated activity, in which design problem-solving, tools and space usage depend on the fluent deployment of intuitive knowledge about mutual awareness, shared perception, information persistence and movement.

Keywords: design for learning, teachers, technology, multi-touch, design, face-to-face collaboration

Introduction

Most established design professions rely on conventional forms for representing finished and in-progress designs. Many of these are graphical such as sketches and blueprints (Li et al., 2005). There are some penetrating analyses of these visual representations and their relations with design thinking and the tools used (Buxton, 2010). There is also strong evidence favouring *collaborative design*: to ensure that expertise which is distributed among different specialists can be combined, and to ensure that the different views of multiple stakeholders are addressed (Arias et al., 2000; Li, et al., 2005). In these more established design professions, use of computer-based tools to aid design is also commonplace, making it easier to work with graphical representations of design ideas and also to collaborate (Kvan, 2000; Li, et al., 2005). There has been a small vein of research on visual languages in educational design (Botturi & Stubbs, 2008) and a 30 year history of R&D on tools for educational design, but take-up of tools and methods by practitioners has been limited (Conole, 2013; Goodyear, 1997; Laurillard, 2012; McKenney, 2005; Prieto et al., 2014; Tennyson, 1994). And despite a renewed interest in teachers as designers within the CSCL community, coupled with a strong focus on design aids such as collaboration scripts, there is still little empirical research on how people use such tools and methods when designing for others's learning (Ertmer et al., 2013; Fischer et al., 2013).

This paper reports on a strand of our research which aims to find better ways of supporting educational design activity (design for learning) by: 1) iteratively prototyping a studio space customised for collaborative design; and 2) observing and analysing the work of users of that space. We have been guided by recent research in CSCL on forms of co-located collaborative learning that involve interactive surface devices, in increasingly richer ecologies: e.g. interactive whiteboards, tabletops, tablets, mobile devices (Evans et al., 2014). Interactive surfaces and spaces provide new opportunities for co-located collaboration as they are intrinsically designed as shared interfaces, allowing simultaneous input from multiple users and facilitating physical interaction, direct communication and mutual awareness (Evans et al., 2014). These are key factors for successful collaborative learning (Dillenbourg, 1998) and collaborative design (Thompson et al., 2013).

Specifically, we explore our participants' use of space and tools in the multi-surface design studio. The task we set them steered them towards using a multi-touch interactive table, but its use has to be understood in the broader ecology of other surfaces and other tools and resources available to them in the studio. We collected multiple streams of data (video, audio, log files of the application use, interviews and questionnaires, as well as the final designs produced by participants). The study involved four pairs of participants, with each pair (or dyad) having exclusive use of the studio during its design session.

The rest of the paper is organised as follows. The next section explains the approach we are taking in our research. It has some unusual qualities, which distinguish it from some more conventional approaches to developing and testing collaboration technologies. Then, we describe the multi-surface setting, present the empirical research conducted for this paper, draw some conclusions and make suggestions for further research.

Approach

The paradigm to develop our multi-surface studio draws on *design anthropology* (Gunn et al., 2013) and on methods for the improvement of learning settings that take a *self-improving ecologies* perspective (e.g. Ellis & Goodyear, 2010). The design anthropology approach involves close study of work practices, including tools, goals, values, skills, division of labour, *in situ*. The self-improving ecologies approach similarly tries to situate the knowledge for design and improvement *within* a system, rather than on top as some kind of external control mechanism. Thus, our primary goal is not to demonstrate the generalisability of the findings of studying collaboration in the multi-surface space. Rather, we investigate whether, how and why new tools find a place within the ecology of the studio, meshing with existing tools and resources, and with workflows, group member skills, methods, interactions etc. - helping move the whole design studio system in a more productive direction.

We do not assume that our user-designers' working methods, tool preferences, divisions of labour, or expertise are fixed. Neither do we assume that the pre-existing configuration of tools has to be maintained. We take collaborative design to be an *emergent activity* shaped in both powerful and subtle ways by the nature of the design task, its interpretation by the designers, the tools that come to hand, skills, divisions of labour, etc. Given that our overall goal is to improve design for CSCL, lessons learned in any one experiment at the design studio can have implications for the studio itself and the tools within it, and/or for the working methods used by designers, and/or for the skills that they need, and/or for the composition of design teams, role definitions, etc. In short, improving how people collaborate to design for CSCL can be achieved through enhancements to any of these components. To simplify the structure of the design activity, we use the activity-centred analytic framework of Carvalho and Goodyear (2014). This specifies the architecture of the situation in which activity unfolds in terms of the ways that activity is *physically*, *socially* and *epistemically* situated. As researchers aiming to support collaborative design for learning, we can manipulate each of these three loosely coupled components, while recognising that they will be reconfigured by our designers in the actuality of their work.

We suggest that a proper understanding of design activity depends upon close observation of how design team members use tools and other resources to accomplish their work. Following distributed but interwoven activity across heterogeneous (digital and material) networks of people, tools, artefacts is how a satisfactory description of design can be created. Our description includes some straightforward measures of the usage of the various tools available, and of the space within the studio itself. It is useful to know such things as what tools were used, for how long and for what purpose; which tools were used rarely or were left totally unused; and how people made use of the space. However, to understand the tools and space usage in the context of the activity, it is also necessary to examine the mutually-shaping relationships between the physical, social and epistemic. We illustrate some key inter-relationships in the latter part of the paper.

The Multi-touch Tabletop in the Multi-surface Design Studio

The Design Studio is a space located at The University of Sydney equipped to support teams of designers engaged in 'design for learning' activities. The Design Studio brings together a number of tools, including digital and material resources, which can be used to facilitate the work of designers. For the case study presented in this paper, we enhanced this environment with the addition and interconnectivity of multiple surface devices. We refer to this enhancement as the *Multi-surface Design Studio*. Figure 1 illustrates the physical tools available in the *Multi-surface Design Studio*. The space features: a multi-touch tabletop (enhanced with a system that can discern the identity of the user touching it, see Martinez-Maldonado et al., 2011) placed on a regular large table, an interactive whiteboard (IWB), a wall painted in whiteboard paint (writeable wall), a pair of tablet devices each connected to mounted projectors mirroring the tablet interface to each wall, and a set of materials such as paper, pens, post-its etc. Figure 2 shows the Design Studio in use and the user interface that can be displayed on either the interactive tabletop or the IWB. The prototype design software developed for this study is grounded on research-based knowledge about learning design tools that are (typically) oriented to single user-designers, but with adaptations for our intended scenarios of collaborative design use (Nicolaescu et al., 2013; Prieto et al., 2014). The principled features of the design tool are as follows:

1. **Support for simultaneous input and awareness for collaboration**. Nicolaescu et al. (2013)'s recent work suggests that collaborative design for learning, when performed online, can present awareness challenges (e.g. it is not *easy* for designers to know what the others are doing). One key feature of interactive tabletops

and IWBs is that, if the interaction mode is based on *direct touch*, it enhances the awareness and accountability of group members' actions (Evans, et al., 2014). Our prototype exploits the capabilities of the hardware to provide interface elements that can only be manipulated by direct touch (touch buttons and drag/drop gestures), which are within reach of users even if located on opposite sides of the table (Figure 2, top-left).
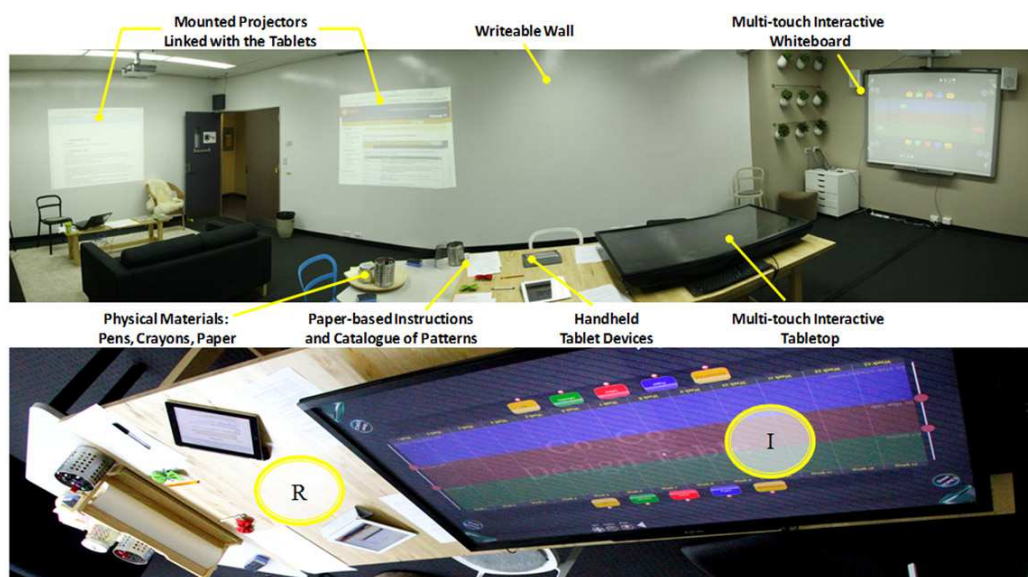
Figure 1. The Multi-surface Design Studio featuring: a multi-touch tabletop, an interactive whiteboard, writeable walls, two tablets each connected to mounted projectors, and various physical materials such as paper, pens, etc. RT: regular table. IT: interactive tabletop.

2. **Provision of a pattern language.** Prieto et al. (2014) reported that teachers value the provision of templates and accessible vocabulary to speed up design for learning. Design patterns can, in principle, be used to address this because they are a general reusable solution to recurring problems within a given context (Alexander, 1999). They have been widely used in architecture, manufacture and software design but are still relatively uncommon in education (Hernández-Leo et al., 2007). As with some desktop/web-based tools for learning design (Hernández Leo et al., 2005) in our prototype, a pattern language (PL) can be defined for the teachers to use pre-existent patterns as templates. For example, Figure 2 (bottom-left) shows some *instances* of the patterns (e.g. see coloured squares labelled as *Lecture*, *Laboratory*, *Group Formation, etc*) that were placed by the users on the design space by dragging and dropping *pattern templates* from a *pattern catalogue*.

3. **Provision of the notions of workflow and learning spaces.** Our prototype provides the use of position as a representation of time (e.g. a flipped-timeline is provided to associate learning tasks on a weekly basis, see Figure 2, bottom-left, the timeline goes from left to right in the figure). Additionally, it also provides the use of regions on the interactive space to associate learning tasks with student's learning spaces (see blue, red and green horizontal bars in Figure 1 (bottom) for the *classroom*, *laboratory* and *home* spaces.

4. **Provision of a hierarchy of tasks.** Workflows of sub-tasks can be defined as parent tasks that can have various ordered child tasks that can also contain workflows (see Figure 2, bottom-right, a user defining a task's workflow). This structure is inspired by the tree-like structure of pattern languages, the IMS-Learning Design specification (Britain, 2004), and similar desktop-based learning design tools (Prieto, et al., 2014).

5. **Representation of the design at different levels of detail (semester/weekly views).** The prototype can be configured to allow the design of a whole university course (e.g. courses in the host university that commonly consist of 13-14 weeks - see *semester view* Figure 2, top-right). Teachers can navigate to design in detail the workflows of the tasks in the chosen week (e.g. *weekly view* Figure 2, top-right).

6. **Allowing both guidance and flexible design paths**. Prieto et al. (2014) report that teachers perceive that design for learning tools should provide scaffolding to perform quick designs. However, the ultimate decision of opting to follow the scripts or suggested templates would not only depend on the features of the tool but also on the nature of the design task and the distribution of roles and expertise among the designers.

For this, our prototype provides the option for users to create their own patterns and edit any proposed templates as required. Any number of physical keyboards can be attached easily, to allow rapid multiple-user text input.

7. **Association between syllabus topics and patterns.** The prototype provides a representation of syllabus topics so the learning tasks can be associated with specific topics on the syllabus. For example, Figure 2 (top-right) shows a number of labelled yellow squares aligned at the top of the IWB that can be dragged and dropped onto specific patterns to create for example the main topic(s) of a *Lecture* or a *Seminar*.

Figure 2. The multi-toch prototype displayed in the tabletop and IWB
Top-Left: participants face-to-face at the tabletop. Top-Right: participants working on the *semester view* at the IWB. Bottom-Left: partial snapshot of pattern instances placed on the *semester view*. Bottom-Right: participants designing the workflow of two instance patterns in the *weekly view*.

Participants and study description

We conducted a series of experiments consisting of design for learning activities in our multi-surface design studio. Four dyads (A, B, C and D), with different levels of teaching and learning design experience, and who had worked together before, participated in the study (6 females and 2 males, aged 35.7 (±9) years on average). Their goal was to produce the high level design of a Unit of Study (a 13 week course) and the detailed design of at least two selected weeks (weeks 5 and 6) for an existing subject in the area of Information Technologies held at the host university. Participants followed a 30 minute tutorial that consisted of a series of steps to build a sample design, covering all possible actions that could be performed using the interactive tabletop and the IWB. Afterwards, participants were given up to one hour for the actual design activity. The average of the duration of the four collaborative sessions was 50 minutes (±2). This was followed by semi-structured interviews with each dyad (20 minutes). In addition, each participant responded to a questionnaire asking about the usage (or lack of usage) of the tools and space available in the design environment.

Each participant was given the following paper-based materials: the *task script* (consisting of the requirements and constraints that participants had to consider to accomplish the design tasks); and a *catalogue of learning tasks* (including some CSCL tasks and which was a simplified Pattern Language describing what each pattern was about in the context of the course). Each participant was also provided with the following digital materials displayed in a tablet: a digital copy of the *task script;* a digital copy of the *catalogue of learning tasks*; and access to the CUSP, which is an online system that provides the official description of courses in the

host university (it shows the topics, teaching rules, learning goals and a tentative schedule for specific courses). The interactive tabletop and IWB were mirrored so all the changes in either interface were immediately updated in both displays. The initial disposition of the tools and space in the design studio was the same for all the sessions (see Figure 1). Participants were told they could rearrange the furniture freely, if they needed.

To perform the analysis, we triangulated manually captured quantitative evidence about tools and space usage with the qualitative explanations from participants' interviews and questionnaires. We captured video recordings of each session and we manually recorded the time and duration of the moments when each participant interacted with a specific tool and moved to a different physical space within the design studio.

Analysis and discussion

We started the analysis of the relationship between tools usage, the group dynamics and the task, by looking at the quantitative traces of tools' usage. First, we calculated the duration of each participant's interaction with the tools available. Results showed that the most used tools were the interactive tabletop, the paper-based task script and the tablets (with an average of 27 ($\pm$5), 22 ($\pm$6), and 12 ($\pm$1.5) minutes of usage per participant respectively). Figure 3 (left) shows the distribution among dyads in terms of usage time. It shows that other tools were scarcely used - and only by one or two dyads. These were the IWB, the paper-based glossary of patterns and the projectors mirrored with the tablets. The other non-digital tools were never used for this task; that is, the writeable wall or the paper and pencils. In previous studies, the writeable walls have been used extensively. As we explain below, tasks which involve discussions in larger teams of alternative designs in upstream/conceptual design work seem more likely to be accompanied by use of the writeable walls than do situations like the current one, where a dyad is working quickly on a more convergent, downstream design task.

Figure 3. Tools usage.
Left: Tools usage time per dyad. Centre: Dyad A diving labour in different devices.
Right: Dyad B working side-by-side at the tabletop

The ways in which tools were used varied widely among the dyads, as we illustrate in the following analysis. Participants often interacted with more than one tool at the same time. We measured the proportion of time spent interacting with or looking at two or more tools at a time, (e.g. interacting with the tabletop while holding a tablet or a piece of paper). On average, 61 % ($\pm$11) of the time participants used tools, they used them in conjunction with others. The pairs of tools that were used more often were: *the tabletop and a paper-based task script* (average of 35 % $\pm$17 of the tools usage time by each dyad); *the tabletop and a tablet* (e.g. see Figure 3, right) (18 % $\pm$3); and *a tablet and a paper-based task script* (5 % $\pm$1). For example, one participant explained the use of multiple tools as follows: "*using the tablet and the tabletop at the same time was a really good resource in terms of looking at the schedule, teaching requirements and assessment of the subject being designed*". It is not uncommon for computer-based design systems aimed at the solo user to involve switching between screens/windows to access different information or tools. While it is convenient to have everything in one system, for team-based design work, having persistent displays/availability of all the information/tools required is highly valuable. Shifting gaze from one surface to another is much quicker than negotiating within the team about which information or tools are needed next. Because rapid shifts of gaze are natural in human perception, this ability is taken for granted and goes unnoticed, until there is a hiatus in the flow of the work.

Regarding the use and re-use of the software-based tools, we analysed the use of patterns to achieve the task (*Relationship between tools and design task*). Most participants found it useful to work with patterns (7 of the 8 participants strongly agreed that the provision of template patterns allowed them to effectively configure the course design). One participant explained this as follows: "*being able to directly drag generic tasks into the timeline helped define and refine the design*". However, only one dyad accessed the paper-based glossary of

tasks to seek details about certain patterns (see Figure 3, left, glossary only briefly accessed by dyad C). This behaviour can be explained as follows: part of the task included the substitution of a number of *Face-to-face Lectures* with *Online Lectures* in a number of selected weeks of the course. Only dyad C tried to understand the pedagogical implications and the pedagogical elements that might go missing in swapping these activities. One of the group members explained that "*the catalogue helped [them] understand the trade-offs of substituting online for face-to-face learning activities*". This shows that this type of design thinking can emerge but it was only observed once in one of the four dyads. It suggests that further scaffolding and/or task definition may be needed to encourage better use of this tool and its associated design thinking.

Regarding the usage of the physical space of the design studio, the four dyads behaved differently and, in some cases, re-arranged the furniture provided in the Design Studio *(Tools and space usage)*. Overall, participants mostly worked around the interactive tabletop (77.8% of the total time), and the rest of the time at the regular table (see Figure 1-RT) and the IWB (19.4% and 2.7% of the time respectively). However, the four dyads used the space in very different ways (*Relationship between tools and social interactions*). Figure 4 shows the heatmaps of space usage of the four dyads as captured from the video recordings. Dyads A and C worked mostly face-to-face (f2f), mostly at the interactive tabletop (IT) but also at the sides of the regular table space (RT). In fact, the use of space by dyad A reflected the division of labour they adopted. This pair worked almost separately, without maintaining awareness of the other's actions. They worked in different spaces at different times (for example, Figure 3 (centre) shows how participants in dyad A divided labour working with different shared devices). By contrast, a different strategy of space usage was followed by dyad B who worked side-by-side (SxS) (e.g. see Figure 3 (right) and heatmap corresponding to dyad B in Figure 4). A third case was seen with dyad D, where participants mostly interacted at the interactive tabletop but interspersed moments of F2F and SxS work. Such positioning has implications for both the readability of the text on the table and for eye contact between the designers. Overall, different ways of working - face-to-face or side-by-side – were observed (28.9% and 29.7% of the time for F2F and SxS work among dyads).
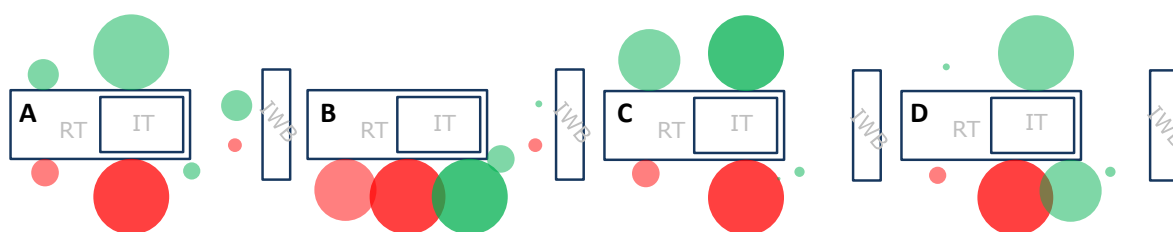
Figure 4. Heatmaps of space usage: the size of each circle represents the amount of time each group member (represented with green or red colours) spent in determined position in the design studio.
RT= Regular Table; IT=Interactive tabletop; IWB=Interactive Whiteboard.

Another interesting aspect of the dyads' activity comes from an analysis of transitions between tools and spaces. The first type of transitions includes how each participant shifted attention between personal exploration of information using the tablets and interacting with the shared devices. For example, Figure 5 depicts three different versions of this, including 1) the rearrangement of the furniture to work side-by-side with each person either holding or sharing a personal device and/or working at the tabletop (e.g. dyad B in Figure 5, left); 2) participants using their personal devices at each side of the table (e.g. dyad C in Figure 5 (centre)); or 3) participants sharing their personal devices to support discussion and mutual understanding whilst working face-to-face (e.g. dyad D in Figure 5, right). Most participants commented on the usefulness of the tablets, for example: "*it was easier to look at the information in the tablet, because you can hold it while interacting with the tabletop. Also the resolution of the tablet is very good for reading*". Additionally, all participants reported that they used the tablets to consult the CUSP (the information about the course), and they preferred to use the paper versions of the task script and the catalogue of tasks. In this way, they preferred to give meaning to the device (e.g. correlating the physicality of the material tool with the logical resource (e.g. the tablet to consult the CUSP and the paper to access the task instructions and requirements) *(Relationship between tools and task*). This was explained by a dyad as follows: "*It was good to have the task script on hand (paper) rather than switching in between using the tablet. It was easier to navigate through the subject resources on the tablet and have the instructions on hand so you can immediately find the information quickly when needed*". In addition to capitalising on the speed with which gaze can be adjusted (mentioned above), this observation also suggests that the participants were using the location of information as a cue to (re)finding it quickly.

Two main behaviours related to transitions within the design studio space were observed: 1) holding or bringing tablets onto the tabletop surrounding, compared with 2) leaving the tablet on the regular table space

and moving to that space when needed. Figure 5 (centre) shows this contrasting behaviour in space, between the members of a dyad. For example, a participant justified her preference indicating that *"it was good to have some space on both sides of the table so we could place the tablet next to it for quickly looking or for grabbing it"*. We could not find any trend between dyads and preference of bringing the personal device to the shared space or moving to where the personal device was placed. For example, the heatmaps in Figure 4 show that mostly participants in dyads A and C and the red participant in dyad B, spent time in the regular table space.

Figure 5. Strategies of usage of personal and shared devices
Left: Dyad B working SxS with moments where participants look at the same personal device. Centre: Participants in Dyad C revising information from the personal devices. Right: Dyad D sharing a personal device whilst working face-to-face.

Finally, the transitions between the Tabletop and Whiteboard were limited. The IWB was used only by dyads A and B. Only one participant in dyad A found it useful to work on the IWB. The rest of the participants found that it was not comfortable to work on the IWB because of the length of the task (e.g. one participant indicated that "*it is more comfortable to work at the tabletop because your arms are down. You need to do more effort to interact with the IWB because you need to lift the arm*") or because it was not easy to see the whole design while interacting with it that close. However, most participants (7 out of the 8), indicated that the interface replicated in the IWB and the tabletop helped them visualise the whole design quickly. This suggests that even though they did not interact with it, they used it to maintain some awareness of the whole design.

Conclusions and future work

We have constructed a prototype for a multi-touch tabletop as a research tool through which we can learn more about how to support CSCL designers: helping them design and redesign quickly using gestures to manipulate iconic representations of pedagogical design patterns. Rather than try to understand the use of the tabletop in isolation, we have studied its use within the larger ecology of a design studio with multiple surfaces and other tools and resources. Rather than try to make assertions about the affordances of a tool (in isolation from considerations of the skills and activities of its users) our goal is to construct an understanding of the relations between tasks, tools and people, and to discern those relations working out in the detail of what people actually do. For example, the task requested teachers to design the semester-long course without inviting them to test alternative candidate designs. Therefore, participants found it handy to use the tabletop to accomplish the task. This helps explain why they did not sketch or use other tools to brainstorm or compare, and test their ideas. This was explained by one participant as follows: "*maybe we could have used other materials if we had to try to complete a new design on paper, pass it to the digital environment using the tabletop and then discuss or present it to someone on the IWB*". On the other hand, each group used the tools in the same proportions, but had different ways to divide labour, share devices, maintain mutual awareness and complete the tasks.

Our next steps in enhancing the Multi-surface Design Studio will be informed by this and other trials, together with insights inspired by other researchers in what are sometimes very different contexts (e.g. Prieto et al., 2014). Rather than seeing others' research as a source of generally true principles from which it ought to be possible to derive specific implications for action in our own context, we can see their work as benefiting our own through a process of translation. It is in that spirit that we offer our own contributions in this paper.

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