# CoCoDeS: Multi-device Support for Collocated Collaborative Learning Design

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**Figure 1. CoCoDes interface embedded in an ecology of devices. Left: CoCoDes in a multi-touch tabletop, Centre: three teachers performing a collaborative design task in our technology enhanced *design studio*; Right: CoCoDes in an interactive whiteboard.**

## ABSTRACT
We propose a novel principled approach and the toolset to support collocated team-based educational design. We scaffold teams of *teachers as designers* creating rapid high-level course designs. We provide teachers with an ecology of digital and non-digital devices, an embedded design pattern library and a design dashboard. The toolset is situated within a purpose-built educational design studio and includes a set of surface devices that allow teachers to manipulate iconic representations of a course design and get real-time design analytics on selected parameters. The contribution of the paper is a description of the rationale for, implementation and evaluation of, an innovative toolset that sits in an ecology of resources to support collocated educational design.

## Author Keywords
teacher support; educational design; design patterns; multi-touch; tabletop; IWB

## ACM Classification Keywords
H5.3. Group and Organization Interfaces: Computer-supported cooperative work

## INTRODUCTION
In this paper we describe the rationale for, and implementation and evaluation of, an innovative educational design toolset. This is centred on a multi-touch, multi-user system that can be deployed in large surface displays (e.g. a digital tabletop and/or an interactive whiteboard – IWB, like the ones featured in Figure 1, left and right), and is situated within an ecology of other digital and non-digital devices and resources (centre). These tools have been created to enable research on collaborative educational design work carried out by small teams of people – typically involving a mixture of academic subject matter experts and professional learning designers. Our research focus has been on design tasks which involve the rapid manipulation of high level designs. That is, we have a particular interest in early stage conceptual design (Cross, 2006). Many of the design support tools that have been created over the years are best suited to later stages in the design process, when the high level ideas have crystalized and it is no longer easy to revisit major design decisions (Paquette, 2013). Premature commitment to design solutions is recognised as a significant source of problems in educational design, so our goal is to help designers to explore a variety of candidate solutions quickly and efficiently (Der-Thanq et al., 2006; Ertmer et al., 2013; Laurillard, 2012).

The CoCoDeS design system (COllocated COllaborative Design Surface) was created to function alongside other support tools in a purpose built *design studio*. We are particularly interested in new forms of design work that are distributed across, and take advantage of, a variety of surfaces (digital, analogue and hybrid) allowing members of design teams to operate on multiple representations of their designs, comparing and discussing candidate ideas as they move back and forth through a design process. Rather than limiting our analysis to look at the user experience or the impact of the CoCoDeS in isolation, our evaluation studies track designer-user activity across multiple tools and display surfaces paying close attention to details of the design task, mobility and users' actions to get insights into how design team members are dealing with the very complex problems of educational design in the ecology of resources and support tools.



OzCHI '16, November 29 – December 2 2016, Launceston, TAS, Australia

http://dx.doi.org/xx.xxxx/xxxxxxx.xxxxxxx.

## BACKGROUND

### Learning Design

Research into design cognition generally, and also into the thinking processes that are involved in designing for other people's learning, show design to be a very demanding form of human activity (Cross, 2006; Ertmer et al., 2013). Given the frequently-observed human talent for offloading parts of the cognitive work to entities in the environment (Hutchins, 2010), understanding how design tools and display surfaces carry part of the load becomes a significant research problem. We are also interested in getting a better understanding of a characteristic, sometimes overlooked, quality of design work – that it often involves *resolving design tensions*. It is rare for design to be a simple matter of optimisation of a single variable. More often, there are multiple goals, and ways need to be found of balancing competing demands. In educational design, for example, we have to balance low and high level learning outcomes – such as when a learning activity must help students understand a principle in physics *and also* become better at teamwork. To pursue this research aim, our user studies sometimes involve design team members assuming roles that each focus on a specific aspect or area of the design, and design representations which dynamically adjust to provide team members with real-time data on (sometimes competing) aspects of their evolving designs.

Moreover, the intrinsic complexity of designing for other people's learning has been recognised for many years (e.g. Reigeluth, 1983; Romiszowski, 1981). In consequence, there has also been a long history, within educational technology, of research and development aimed at creating better tools for educational/instructional designers (see e.g. Conole, 2013; Paquette, 2013; Prieto et al., 2013; Spector et al., 1993). For instance, *Course Map* (Cross et al., 2012) supports textual outlines of courses; *CompendiumLD* (Brasher et al., 2008) provides a visual interface to represent learning outcomes and tasks using graphs and concept maps; and some design tools scaffold teachers in the authoring of detailed plans for learning activities, ready to be used in practice. Example of these are *Web Collage* (Villasclaras-Fernandez et al., 2013) and *OpenGLM* (Derntl et al., 2011).

Take up of some of these tools has been significant, though it would still be fair to say that they have not had a widespread impact within mainstream higher education practice (Prieto et al., 2014). Most educational design tools, such as those mentioned above, are desktop or web-based *single user* editors. They function in ways that limit their value to design *teams* (with a few exceptions such as *SyncLD* by Nicolaescu et al., 2013). Several reasons have been advanced for this, but there is also a clear need for more targeted empirical research to show how better tools and better working practices can be helped to evolve in combination (Bennett et al., 2015; Masterman, 2015). The work reported in this paper sits in this space.

### Multi-device Ecologies and Cross-Device Interaction

Face-to-face collaboration offers important and well differentiated benefits in comparison with what can be achieved in computer - mediated, geographically - distributed group work (Olson et al., 2002; Wineman et al., 2014). Collocated interaction is particularly crucial for tackling complex collaborative tasks that require rapid generation and flow of ideas and discussion, such as designing (Anderson et al., 2007). However, some difficulties in coordinating collaborative face-to-face work have been reported when multiple people share a single personal device (Okdie et al., 2011). As a result, there has been a growing interest in moving from single device experiences to considering the *ecologies of devices* and *cross-device* interactions needed to support fluid interaction and mutual awareness in collaborative work (Chung et al., 2014; Haller et al., 2010; Houben et al., 2014; Martinez-Maldonado et al., 2016; Perrin et al., 2016; Rädle et al., 2014; Wigdor et al., 2009). Evidence of this has also been the recent workshops organised in HCI conferences focused on discussing collocated CSCW interaction[1] with multi-device ecologies[2] and for designing cross-device experiences[3].

These emerging ecologies often feature intertwined interactivity across physical and digital objects and allow users to interact with the devices while communicating face-to-face. Group members can benefit from the advantages that each device can offer and compensate for their shortcomings. For example, horizontal table displays commonly invite symmetric participation while vertical displays can be better for visualising content or the products of the group (Rogers et al., 2009; Rogers & Lindley, 2004). Similarly, combining tablets and large shared devices to support group discussions may promote the use of pointing gestures and touch across devices (Oleksik et al., 2014) as well as for distributing the cognitive load and keeping awareness of multiple representations (Schmitt et al., 2012).

The use of an ecology of different types of devices for supporting collaborative design work has not received much attention by researchers, and so even less is known about their use in educational design. The approach described in this paper is the first effort we are aware of, that aims at supporting teachers to accomplish face-to-face collaborative learning design using varied digital and non-digital devices. The design of the system and the ecology of devices where it is situated is grounded on six principled design intentions. The rest of the paper provides a description of the core concepts and the implementation of the tool. Then, we present an evaluation of users' experience when interacting with the system to accomplish a real learning design task.

## APPROACH

The development of CoCoDeS and its surrounding tools and design environment has been strongly influenced by recognition of specific sources of cognitive complexity in educational design work (as cited above, and see especially Ertmer et al., 2013; Wardak, 2014). We have also been drawing on lessons learned by international

[1] Collocated Interaction workshop held at CSCW 2016 https://collocatedinteraction.wordpress.com/

[2] 2nd Cross Surface workshop held at CHI 2016 http://cross-surface.com/

[3] Cross Device workshop held at DIS 2016 http://www.cross-device.org/

collaborators who have been developing and testing a variety of tools and methods to support educational design (e.g. Derntl et al., 2013; Hernández-Leo et al., 2014; Prieto et al., 2014). In addition, we have been running a series of experimental studies aimed at gaining insights into educational design activity (Martinez-Maldonado et al. 2015). These have included quite naturalistic studies – working with existing design teams, using their own methods on their own design tasks – and more contrived studies, in which we have provided design teams with tasks and/or tools and/or working methods, to shed light on particular aspects of design activity and its support. Some R&D work in the field of technological support for educational design is focused on the needs of geographically distributed design teams or communities. Our own focus is on co-present design teams. The overarching aim of our research is to evolve a digitally-augmented *educational design studio*, in which small, multidisciplinary teams of co-present collaborators can find ways of working more efficiently, effectively and enjoyably. Our development work is not restricted to enhancing the studio and the tools it contains; we aim to help users co-evolve these, in alignment with improved design methods and design roles (divisions of labour).

**Principled approach: design intentions**

In the run up to implementing CoCoDeS, we held two workshops, involving a number of colleagues who have experience as practitioners and/or researchers in the area of educational design. In the next part of the paper, we summarise six sets of principles that emerged from our distillation of: (a) outcomes from these workshops, (b) the literature cited above, and (c) our preliminary experiences with a beta version of the CoCoDeS (Martinez-Maldonado et al. 2015). These principled design intentions have helped frame the approach to implementing CoCoDeS and the methods for using it.

*1 Support for computer-aided collaborative design*

In other areas of design practice, such as architecture, software development or product design, digital design tools are widely adopted and used (Li et al., 2005; Wu et al., 2015). These are often integrated with each other (e.g. into CAD systems) and linked downstream with computer-aided/controlled manufacturing systems (CAD-CAM) or implemention tools. Despite the popular image of the solo creative designer, these other, more firmly established, design professions have long recognised the value of *collaborative* design (Arias et al., 2000). Thus, they also tend to have collaboration tools and/or shared representational systems – visual languages, standardised notational systems, etc – that enable designs to travel. As yet, the use of design tools is far from being mainstream in higher education practice, even though there are multiple sources of pressure that threaten the sustainability of existing practices (Conole, 2013; Laurillard, 2012). Although there has been some interesting experimental work on visual languages for educational design, these forms of representation are not widely used either (Brasher & Cross, 2015). And although collaboration across disciplines, and between teaching staff and educational designers, have been identified as key to sustainable design practices into the future (Keppell, 2007) there are very few tools explicitly implemented to support educational design teams. To the best of our knowledge, there are only two online educational design tools *for teams* reported in the recent literature: Derntl, et al., 2013; Hernández-Leo, et al., 2014. These considerations informed our view that CoCoDeS should provide support for team-based educational design, including both specific design tool functionalities and also support for divisions of labour and interactions between design team members.

*2 Support for mutual awareness and multiple roles*

Lack of mutual awareness among members of an educational design team is a problem reported in evaluations of one of the current online collaborative educational design systems (Nicolaescu et al., 2013). Without the provision of feedback, it is not easy for users to know what the other team members are doing when they are working remotely. One of the functionalities of using large interactive surface devices (such as tabletops and IWB's), is that they invite all team members to interact with the shared device, and, at the same time, actions become visible to other team members (Evans & Rick, 2014). Similarly, handheld devices can serve to both provide a private interface for single users (Kharrufa, et al., 2013) and also to share information with other team members. A system aiming to support face-to-face collaboration should provide both shared spaces for co-designing *and* tools for private exploration and annotation of information. The system should be flexible enough to support both asymmetric and symmetric team work (Salas et al., 2005). For example, teams of designers may have different roles, leadership relationships, levels of expertise and work preferences (Keppell, 2007).

Therefore, we decided that CoCoDeS should make it easy for teams to switch between periods when all group members can perform actions on the design, and periods when they work on sub-tasks in parallel. CoCoDeS should also allow a team (if it so wishes) to nominate some team members as "doers" while others monitor their actions, providing advice, monitoring displays and/or discussing the implications of proposed changes in the design.

*3 Promote the use of patterns*

Design patterns have been widely used in architecture, manufacturing and software engineering. A design pattern is a reusable solution to a commonly recurring problem, set within a particular context (Alexander, 1999). A series of interconnected patterns that capture good design practices within a field of expertise can be organised as a *pattern language*. *In principle*, the benefits of design patterns and pattern languages can carry over into educational design (Laurillard, 2012; Mor et al., 2014). *In principle*, they can improve design and educate designers by connecting research-based evidence to experiential knowledge (Goodyear, 2005). Although Prieto et al. (2014) and others have reported that teachers value the provision of these kinds of templates and accessible vocabulary to speed up design for learning, actual use of patterns in educational design is still rather rare. Indeed, research has not yet shed much light on the circumstances in which tertiary educators (or learning designers) are likely to use design patterns, or what might be done to make their use more likely and more productive. Hence, as another goal for CoCoDeS, we decided that it should make it as easy as possible for design teams to browse, select and reconfigure some common educational design patterns. Based on some of our earlier work (Goodyear, 2005) we decided to implement in CoCoDeS some sets of patterns concerned with organising student activity (e.g. brainstorming, writing an essay, designing a project), helping students arrange themselves in different forms of collaborative groups (e.g. dyads, triads, tutorial groups, project teams), and ensuring that necessary learning tools and resources would be in place at learn time (e.g. whiteboards, lecture rooms, shared folders, e-prints).

*4 Support for fast outline design work*

It is a central tenet of design studies that the early conceptual phases of design should generate and test multiple possible solutions – mainly as a way of getting a better understanding of, and indeed reframing, the design problem (Cross, 2006). Premature commitment to a specific design is risky and best avoided. In contrast, empirical studies of educational designers show that premature commitment to implementation details is very common, and damaging (Ertmer et al., 2013). In short, CoCoDeS should allow designers to quickly build multiple drafts of the design (candidate designs) and allow smooth navigation between them to compare commonalities and differences, strengths and weaknesses. For example, users should be able to build two candidate designs for the same course: such as a lecture-based design and a blended-learning course design. Another way to help designers to draft designs quickly is, as discussed above, by making the selection and use of educational design patterns as easy as possible.

*5 Support for multiple representations of the design*

Research on “surface computing” - looking at the ergonomics of large, multi-touch displays, for example - has demonstrated the value of *horizontal* shared devices for allowing all members in a team equal opportunities to participate, whereas *vertical* displays are better at providing everyone with a shared, global view of the state of the task (Rogers & Lindley, 2004; Evans & Rick, 2014). Additionally, using alternative representations of the same design is effective in fostering understanding of the different aspects of the same design (Gero & Reffat, 2001) just as one might expect from research on multiple representations in learning (Ainsworth, 2006). For example, dashboards, summaries and visualisations can present the design, as well as estimates of key parameters that may be important at design time. They can make it easier to understand global aspects of the design, shift between the global view and detailed views, and make comparisons with other candidate designs. Consequently, we need to take advantage of the particular capabilities of each device in the design space, including CoCoDeS, to allow user-designers to have, and switch between, different points of view on their evolving designs.

*6 Provide an ecology of devices and resources*

When people collaborate face-to-face they use a wide range of communication channels to negotiate and share their ideas (e.g. talking, gestures with the face and hands, pointing, sketching, handwriting). It also often involves a range of different tools and artefacts (e.g. pieces of paper, whiteboards, smart phones) and depends upon shared social norms. Therefore, in order to deploy a team-based educational design tool into a real design space, we need to take into account the complexity of the collaborative situation, and cannot focus narrowly on the design tools themselves. It is necessary to understand how CoCoDeS will sit in an ecology of digital and non-digital resources, with several user-designers occupying similar or contrasting roles, and with various possible design task definitions.

To simplify the structure of possible design tasks, we use an activity-centred analytic framework (Goodyear and Carvalho, 2014). This framework encourages designers to place intentions about student activity at the centre of their design work, and then to attend to the physically, socially and epistemically situated qualities of student activity. In other words, designers are encouraged to think about what physical (material and digital) resources will be needed by the students in the envisaged learning activity, how students might need to work together, and what forms of knowledge and ways of knowing are implicated in the educational tasks they are to be set. CoCoDeS needs to work with other tools, display surfaces etc in the design studio to make this a more tractable task for educational design team members – for example, by displaying both a design and what it means for the distribution of student learning in time and learning spaces.

In the next part of the paper we describe CoCoDeS as implemented, including information about the user interface, and how CoCoDeS sits within the larger ecology of the educational design studio.

## APPARATUS

### The CoCoDeS user interface

CoCoDeS offers a multi-touch user interface customised to support small teams who are carrying out early stage (high level) conceptual design work on tertiary education courses. CoCoDeS can be deployed on an interactive tabletop and on an IWB. CoCoDeS provides digital elements that can be manipulated by direct touch (by dragging digital objects and touching buttons), allowing bimanual input and fluid interaction with the visual representations of the design. This makes all team members’ actions visible and accountable to other members. Figure 2 shows the main user interface of the CoCoDeS system (the semester view). The central area of the interface is the design area (Figure 2-A) where user-designers define all the learning tasks for students. A pattern language (PL) can be pre-loaded, containing patterns for student tasks, learning spaces, learning resources, etc. Figure 2 shows some instances of these patterns (e.g. see the coloured squares labelled as Lecture in red, Laboratory in green, Project, in blue, etc). These were placed by the CoCoDeS users on the design space by dragging and dropping pattern templates from the bar of template patterns (Figure 2-B).

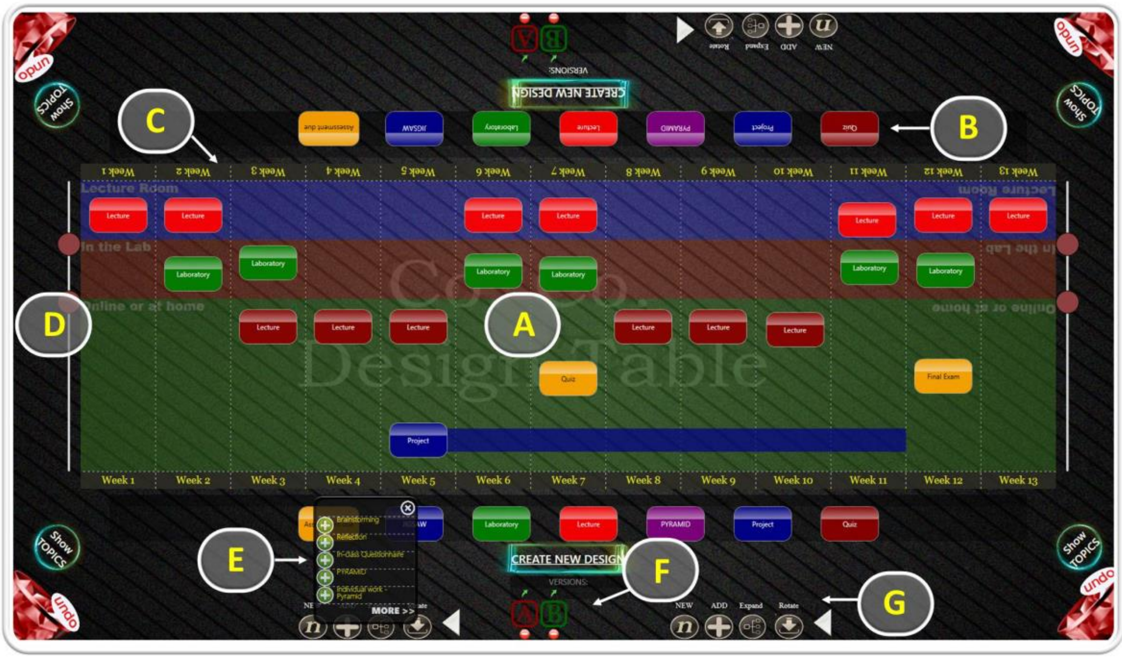


**Figure 2. The semester view. A) editing area; B) bar of quick template patterns; C) weekly timeline; D) swim lanes for the main learning spaces; E) a menu for the catalogue of patterns; F) menu of candidate designs; and G) layout menu.**

The position of the pattern instances on the design area represents both the sequence of occurrence and the learning space where each activity takes place. A flipped weekly-timeline is provided to sequence learning tasks on a weekly basis (C, running from left to right). The horizontal swim lanes associate learning tasks with learning spaces (D, e.g. blue, red and green horizontal bars, for lecture room, lab and online spaces). Layout menus (G) provide access to functions to re-organise the pattern instances, re-orient them towards one of the sides of the interface and add a pattern instance from the pattern language (E). The interface also provides a menu to create new candidate designs and navigate through the candidate designs created by the team (F, e.g. see A and B buttons, representing two candidate designs being worked on by the design team). When a designer touches a digital representation of a pattern instance, a number of optional functions are activated (see Figure 3, top-left). The pattern can be deleted or some of its properties edited. Figure 3 (bottom-left) shows the editing window that allows designers to change the week or weeks when the pattern instance occurs, the colour of the visual representation, the duration, and the exact day of the week when it takes place. Designers can add workflows or embellishing patterns to any pattern instance (see Figure 3, top-right). The workflows in pattern instances can have various ordered child tasks, which in turn can also contain sub-workflows (e.g. see, Figure 3, bottom-right, a user creating a task's workflow).

The designers can navigate to any specific week, in order to either design or view details of the patterns instances linked to the tasks that occur in that week. Figure 4 shows the weekly view for week 11. For example, this shows three main learning tasks (A1, A2 and A3) which contain learning tasks belonging to the pattern Pyramid (see pattern instances in fuchsia). In the weekly view, the interface provides more space for the designers to manipulate the workflows and define the tasks for that week in more detail. The system also provides a representation of learning topics or goals, so the tasks can be linked with real topics or goals as listed in the syllabus for the course. Figure 4 (right-C) shows the visual representation of topics that were linked to two specific learning tasks by dragging and dropping the topic onto each pattern. The topics are loaded from an online system developed at the host university that provides detailed descriptions of courses. This includes descriptions of topics, learning goals, teaching guidelines, assessment rubrics, and a schedule for each course.

### Implementation in the design studio

As mentioned in the introduction, CoCoDeS has been implemented to operate in a design studio. This design

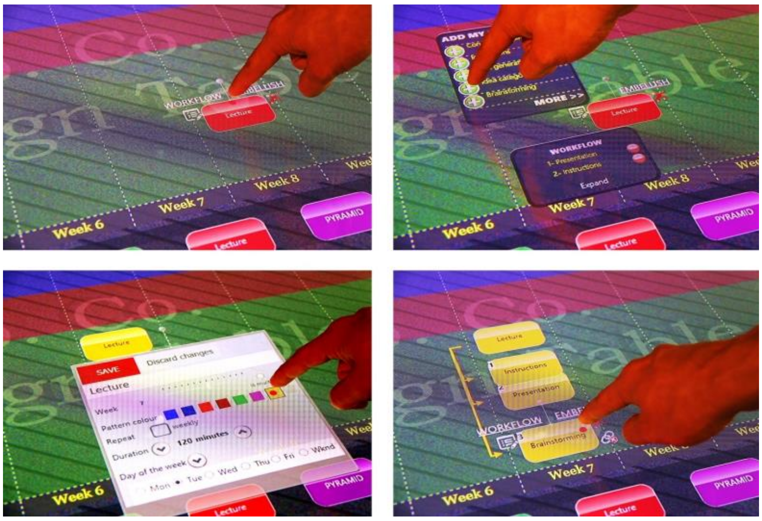

**Figure 3. Actions performed on patterns. Top-left: when a pattern is touched, options for deleting (a red cross), editing (white square), adding a workflow and embellishment patterns appear; Top-right: when the option for adding a workflow is touched, a list with the pattern language appears; Bottom-left: interface for editing a pattern instance; Bottom-right: a user dragging one of the three child pattern instances ("Brainstorming") of the workflow of the pattern "Lecture".**

studio is equipped with a range of digital and physical tools and surfaces, with function-specific areas and various items of furniture to support the collaborative design activity of small teams. Figure 1(centre) illustrates the area of the design studio in which CoCoDeS currently sits. It features three shared digital devices. There is the interactive, multi-touch design table itself (a 40’’ PQlabs overlay was used in the studies - PQ labs http://multitouch.com/) plus an interactive whiteboard (a projection based SmartBoard was used in the studies - Smart technologies http://education.smarttech.com/). This configuration allows user-designers to: i) use the tabletop as the main working device, keeping the semester view on the IWB, ii) split the task so different group members can build two candidate designs in parallel or iii) compare two different designs, each showing on a different device. The third shared device is a dashboard that shows real-time quantitative indicators relating to the candidate designs created in the CoCoDeS system. These indicators include i) a list of patterns added to each candidate design, ii) a pie chart that shows the total student time dedicated to each learning space, and iii) a histogram showing the student load for each week of the semester. When necessary, multiple physical keyboards can be attached to both the shared displays, to allow faster input by multiple users (e.g. so designers can define their own task names or edit pre-existing patterns).

The design studio space additionally features a large writeable wall; a personal computer with a projector; paper, pencils, coloured markers, etc. These are all optional tools for use by the user-designers. Also, the design studio has a built-in audio-visual recording infrastructure to capture research data. During experimental design sessions, multiple radio lapel microphones and ceiling-mounted video and high definition time-lapse cameras record the design activity, including design conversations, for analysis by our research team after the event.

## STUDY DESIGN

The functionalities and validation reported in this paper are a response to the implementation of the design drivers listed above, that lead to the implementation of the CoCoDeS tool and its deployment in the educational design studio. Four teams (teams 1, 2, 3 and 4), of three users participated in an observational study. Participants were recruited by word of mouth from the Faculty of Education of the University of Sydney. Team members had various amounts of teaching and educational design experience, and knew each other beforehand (1 or 2 of them had previous experience with CoCoDeS; the other team members had experience in the design studio – prior to the creation of CoCoDeS). The goal for teachers was to produce two candidate high-level designs of an actual 13 week course in the area of Engineering, held at the host university, satisficing some competing design goals. Each team member was given one of three possible roles (Lecturer, Learning Designer and Quality Assurance Officer). According to their role, each user-designer had specific information about the course and goals. Some of the goals provided to the participants complemented others’ goals, and some were conflicting (e.g. they had to build two of three possible course modalities: a lecture-based, a blended learning or a fully online-based course). Thus, the task involved the resolution of conflicting information and goals, agreement about the different design versions to be built, compliance with institutional metrics (e.g. a minimum of face-to-face contact between students and instructors), and the construction of the designs using the CoCoDeS tool. All teachers were given the following paper materials: a design brief (indicating the requirements and constraints of the course design) and a catalogue of patterns (a simple pattern language describing relevant patterns for the course). Besides the shared tools available in the design studio (listed in the previous section), each teacher was provided with a tablet device that included: digital copies of the design brief and the pattern language, and access to the official online system that provides detailed descriptions of university courses. After the team design activity, a 20-minute semi-structured interview was conducted with each team of designers. Then, each participant completed a questionnaire where they were asked about their experience in the design studio.

## RESULTS

In the next subsections we triangulate evidence from 1) application logs; 2) systematic observations (which included counting the number of times and duration each participant interacted with a tool in the space or when they used the tabletop or the IWB as screens); 3) higher level observations of the group design process (focused on observing the main tools used for i) hands-on work and ii) information seeking; iii) participants’ mobility in the design studio; iv) the level of roles differentiation; and v) the approach to the design process); 4) participant’s questionnaires (with 7-point likert scale questions corresponding to each of our design intentions); and 5) interviews, to provide a discussion about how each principled theme that motivated the implementation of the toolset played during the studies with users.

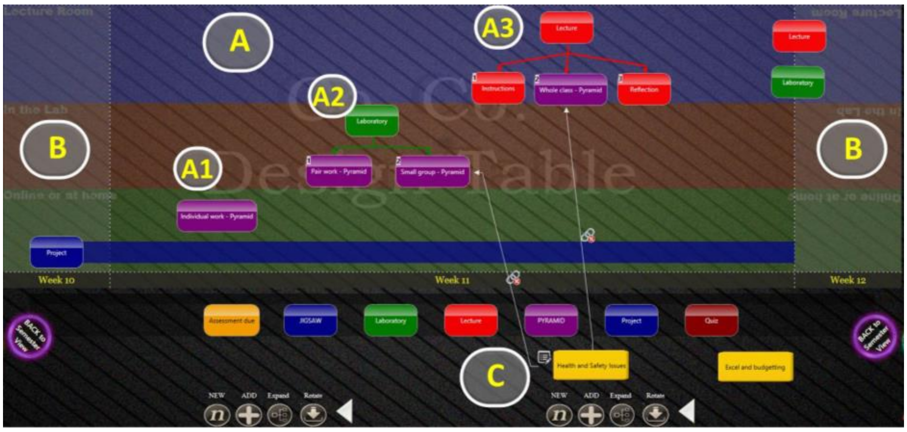


**Figure 4. The weekly view A) editing area with three main pattern instances indicating tasks that occur in different spaces in week 11; B) overview of the previous and next week, allowing users to navigate to those weeks when touched; and C) topics linked with specific learning tasks.**

**Table 1. Accumulated effective time (in minutes) of members of each team using or looking at (gaze only) the tools in the Design Studio, by role: L: Lecturer, LD: Learning Designer, and QA: Quality Assurance Manager.**

| | Team 1 | | | | Team 2 | | | | Team 3 | | | | Team 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tools / Roles | L | LD | QA | Total | L | LD | QA | Total | L | LD | QA | Total | L | LD | QA | Total |
| 1-Tabletop | 28 | 39 | 19 | 86 | 5 | 9 | 12 | 26 | 27 | | | 27 | 13 | 13 | 4 | 29 |
| 2-Tabletop (gaze only) | | | | | | | | | 4 | 16 | 16 | 36 | | | 3 | 3 |
| 3-IWB | | | | | | 8 | | 8 | | | | | 21 | 15 | 9 | 45 |
| 4-IWB (gaze only) | | | | | 5 | 3 | 3 | 11 | 1 | 1 | 1 | 4 | 3 | 6 | 7 | 16 |
| 5-PC with Projector | 13 | 6 | 4 | 23 | 13 | 11 | 13 | 36 | 13 | 4 | 15 | 32 | 1 | 2 | 4 | 7 |
| 6-Dashboard | 1 | 1 | 2 | 3 | 2 | 1 | 2 | 4 | 2 | 4 | 4 | 10 | 3 | 1 | 4 | 9 |
| 7-Tablet - Pattern Language | 1 | 24 | 3 | 28 | | | | | | 13 | | 13 | | | 3 | 3 |
| 8-Paper - Pattern Language | 2 | | | 2 | 5 | 9 | | 13 | | | 1 | 1 | | 11 | | 11 |
| 9-Tablet - Course description | 3 | 1 | 7 | 10 | 2 | | | 2 | | 15 | | 15 | | 8 | | 8 |
| 10-Paper - Course description | 10 | 11 | 21 | 42 | 33 | 38 | 29 | 99 | 5 | 2 | 16 | 23 | 28 | 25 | 22 | 75 |
| 11-Write on Wall | | | | | | 3 | 8 | 11 | | | | 0 | 5 | 8 | 15 | 28 |
| 12-Write on paper | | | | | 2 | 2 | | 4 | | 1 | 4 | 5 | 4 | 1 | 3 | 7 |

*1-Support for computer-aided collaborative design*. According to the post-session questionnaires, most designers strongly agreed that the ecology of devices allowed them to collaborate as a team (6.4 ±0.5, 7-Likert scale). In words of members of Teams 1 and 4: "*What I liked the most was working as a team to accomplish the design task*"; "*I really liked the system because it allowed us to do good teamwork and use it as our own thinking space*". Table 1 presents results of the analysis of tools usage (holding or interacting with the tool) and attention (focusing the gaze on the tool) in each team. This helps understand how the ecology of devices was used by teachers in varied ways to accomplish the collaborative task. Overall, the paper-based course description was used the most (avg: 26%, ±10), followed by the interactive tabletop (20%, ±13 use; and 6%, ±6 attention), the personal computer projected on the wall (12%, ±6 attention), the tablets (10%, ±8 use), the IWB (5%, ±5 use; and 3.3%, ±2 attention) and the writeable wall (4%, ±4 use; and 4%, ±4 attention). Other tools were also occasionally used.

People used the tools to differing extents and often more than one tool was used at the same time. For example, the only tools that everyone used were the PC projected on the wall, the design analytics dashboard and the paper-based course description (rows 5, 6 and 10). Almost all users interacted with the tabletop (except by some members in Team 3, row 1) and only members of Team 4 and 2 interacted with the IWB (row 4). The IWB was mostly used as a non-interactive display by Teams 2, 3 and 4 (row 4). Teams 2 and 4 used the wall to list their design objectives and have them available while working on the digital devices (row 11). This accords with the observations of the design activity which indicated that most of the actual design work happened around the interactive tabletop for most groups with the support of other tools (see Table 2, columns i and *iii*); and the large displays and the writeable wall were used as containers of information needed for the design (row ii). In words of a member of Team 3: "*What I liked the most was working around a table, sharing ideas and portraying them visually for further discussing. This makes the task less abstract and more interactive than having just one modality of design alone*". In short, we obtained evidence that suggests that the availability of different ways to access information and multiple interaction modes were welcomed by the teams to accomplish the group design task. Next, we provide a further description of the rest of the design drivers, which attend to more specific aspects of group work and to particular tools in the design environment.

*2-Support for mutual awareness and multiple roles.* Users agreed that designing face-to-face allowed them to keep mutual awareness of each other's actions while achieving their personal goals (6 ±0.6). In this regards, a member of Team 3 explained that "*the conjunction of the tools available in the design studio helped [their] group by displaying implicit and tacit knowledge and experience of other [team members]*". Another member of the same team added that "*the tools available [also] helped [them] to be more aware about the evolution of [their] designs*". Moreover, observations of the teams' activity showed that not all groups had a high differentiation of roles (See Table 2, *iv*). For example, Team 1 did not show a strong enactment of roles, and the tools usage also reflects that all participants used the same set of tools to similar extents (e.g. see Table 1, Team 1). By contrast, members of Team 2 had a leader who dominated the design task (the Lecturer) and those in Teams 3 and 4 enacted their roles more strongly, leading to more varied tool usage. Thus, these results suggest that the system allowed users to maintain mutual awareness of each other's actions and the progress of their designs, while providing flexibility for them to enact different roles and achieve individual goals.

*3- Promote the use of patterns*. We obtained a mild agreement that the provision of an explicit pattern language useful (4.8 ±1.1). The pattern language was only occasionally accessed, mostly by the Learning Designer (LD) in each team, either at the tablet (Table 1, row 7) or in the paper format (row 8). The LD in Team 2 explained that: "*the [pattern language] helped [them] understand the trade-offs of substituting online for real-time [face-to-*

**Table 2. Overview of observations of the groups in terms of: Overall tools usage, Attention, Mobility, Roles and the Process. f2f= face to face. sxs= side by side.**

| Teams | Observations | | | | |
|---|---|---|---|---|---|
| | i) Tools used for design work* | ii) Tools used to seek information* | iii) Space and mobility | iv) Roles | v) Process |
| Team 1 | Tabletop | Projector | **Fixed:** SxS at the tabletop | Low differentiation | **Linear** work |
| Team 2 | Tabletop, IWB and Wall | IWB, Wall | **Variable:** 1 at IWB, f2f/sxs at the tabletop, sxs at the Wall | Loose enactment Strong Leader | **Parallel** and **Linear** work |
| Team 3 | Tabletop (1 member only) | Dashboard, IWB, Projector | **Fixed:** 1 f2f and 2 sxd at the tabletop | Strict enactment | **Linear** work + meta-analysis |
| Team 4 | Tabletop, IWB, dashboard and Wall | Dashboard, Projector, IWB, Wall | **Variable:** sxs at all the large devices | Strict enactment, distributed workload | **Parallel**, **Iterative** work + meta-analysis |

* some details are not shown (e.g. tablets and paper materials usage)

*face] learning activities*". All the learning tasks and sub-workflows in the CoCoDeS interface are based on learning design patterns. However, users were not necessarily aware that they were designing with patters. Although users did not have a full understanding of the notion of designing with patterns, some of them acknowledged the positive effect of reusing learning tasks offered by CoCoDeS. This was illustrated by one person who explained that: "*being able to directly drag generic tasks [template patterns] into the timeline helped [them] define and refine the design*". This reflects the problem of using formal notation systems and visual languages which are still rare in educational design (Prieto et al., 2014).

*4-Support for fast outline design work*. Designers mildly agreed that they could complete their two candidate designs in the time allowed (5 ±1.1). The four teams completed 2 out of the three possible designs that they were asked to tackle. In terms of quality, they all outlined the semester view of the two candidate designs, completed the detailed designs of tasks for two selected weeks. However, only two teams (3 and 4) compared the advantages and disadvantages of both designs using the large displays and the dashboard (see meta-analysis in teams 3 and 4, Table 2, column *v*). Thus, CoCoDeS allows the fast outline of learning designs. However, the working methods of each team strongly shaped their design activity. For example, members of team 4 worked in parallel, whilst members of team 3 did not, but both groups strongly differentiated their roles to achieve the task. A deeper analysis of design methods is beyond this paper, but the observations suggest that further support for the working methods may improve users' sensemaking by inviting them to compare designs at a meta-level.

*5-Support for multiple representations of the design*. Users agreed that the provision of multiple devices to represent different aspects of the learning designs highly supported their design work (5.8 ±1). The teams that exploited the advantage of the multiple displays the most were Teams 2, 3 and 4 (Table 1, rows 2 and 4, and Table 2, columns *i* and *i*i). One person in Team 2 described the synergy of using the IWB and the Tabletop (and the information about the course displayed in the projected PC or the tablet) as follows*: "the tabletop in conjunction with the IWB made it easy to work and get an overview of the two designs. The tablet made all the resources that were originally in paper more accessible while working on the designs*". A member of Team 4 also highlighted the ability to combine the digital tools with *analog* handwriting on the white walls to shape their learning design strategy: "*I really liked to write in the white walls but the combination of IWB, White walls and Tabletop is excellent for distributing phases of design*". The dashboard also provided yet another view with concise information to compare both designs at a glimpse. In words of members of Teams 2 and 3: "*The dashboard provides a great overview of the whole task*" and "*What I liked the most was the flexible mode of presentation via the tabletop – combined with the dashboard visualisations to keep our design on track".*

*6-Provide an ecology of* devices *and resources*. Users agreed that the provision of an ecology of digital and non-digital tools supported their design process (5.8 ±1). One encouraging outcome from these studies was that every team was able to complete a challenging design task within a brief period – less than an hour of design activity in many cases. In addition to completing the design task efficiently, analysis of the distribution of their activity (Table 1) showed that they used a wide range of tools and resources. One of the users highlighted that "*the design of the physical space allows freedom of movement and facilitates the usage of the tools*". Thus, the functionalities of CoCoDeS are not just inherent to the application or interactive surfaces, but to the ecology where it sits. People commonly refer to the whole ecology of devices as 'the tool' that allowed them to efficiently perform the collaborative learning design task, rather than specific tools. One user described this as follows: "*I liked the way we used the tools in conjunction: the [CoCoDeS] system at the IWB, the dashboard, and specially, the writeable walls*". Another user in Team 1 also highlighted less frequently-mentioned tools such as the paper-based materials and tablets as crucial to complete their task: "w*hat I liked the most was working at the tabletop combined with using the ipad and paper to get information about the course we were designing*"

## CONCLUSIONS AND FUTURE WORK

In this paper, we have described a novel set of tools, embedded in a design studio, whose use in experimental studies is shedding light on educational design activity, design thinking, and the interaction between designers and tools in design tasks. These design tools are situated within an ecology of devices, material objects and digital resources to enable team-based design work. The purpose is to provide to user-designers with a wide variety of tools that they can choose to facilitate their design work and take advantage of the different functionalities that each technology offers (e.g. multi-touch manipulations, regular computer interaction, or materials to write notes on non-digital formats). Moreover, in the questionnaires and debriefing interviews, users reported experiencing a good fit between the tools and the requirements of the task. Particularly pleasing, in this regard, was the frequency of interview comments that spoke of the ease of movement across the various tools, surfaces and spaces of the design studio, with the CoCoDeS table at its heart. Feedback also included ideas for further elaboration of the meanings of some of the digital elements in the CoCoDeS display – for example, suggesting that icons representing instances of design patterns might take on a size proportional to the duration of the student learning activity they entailed. This can be taken as just one example of how experimentation with a prototype design tool can help power the evolution of both the tool and the design practices in which it figures. Future work will investigate ways that people appropriate the use of the tools and space available: considering the social roles, divisions of labour and particular elements of the task that shape the face-to-face collaborative educational design activity.

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