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Processes of design and tool use in the development phase of the CoCo Design Day

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Executive Summary

This working paper reports on the results of research carried out between June and October 2012, based on the ‘Water in the Landscape’ project, funded by WSROC (Western Sydney Regional Organisation of Councils). As a result of this research, two papers have been submitted for further publication.

Enabling school students to understand complex systems is challenging and providing engaging tasks, through technology enhanced learning, that support collaboration can be beneficial. One method of learning, ‘Learning by design’, has a long association with learning about complex, environmental systems. However, there is still much debate over how best practices for this type of learning can be identified.

There is still a need to examine and understand the processes of learning, that students go through, when engaged in a ‘learning by design’ activity. Students use many different tools while completing a ‘learning by design’ activity; to help design better tasks, it is important that the complex interactions of both physical and digital tools is better understood. As the tools become more sophisticated and specialized they are playing a greater role in face-to-face collaborative learning situations. This working paper focuses on two aspects of one group of students as they undertook a collaborative design activity:

1. A look at the way in which the students were using tools (tablet computer and whiteboard) including an analysis of group’s sketching activities.
2. The process of design, the role of idea development, and the facilitator’s impact on the processes.

Three groups of four to five students were asked to undertake a design challenge to create an online educational resource about a waterway of local significance. The groups were recorded during the ideate phase of a design process. They carried out this design work in a multimedia design space, using a whiteboard wall as well as a tablet computer (projected onto the wall). In these papers, we studied one group during a forty-minute session. Their task was to develop their ideas about the design. After a break they were expected to present their ideas to the other groups.

From the video and audio data collected, ideas important to the progression of the design were identified, and represented visually, as they developed over time. It was found that the roles of all members of the group were important to this development, as was the role of the facilitator. The conversations between members of the group and with the facilitator were analysed using the CPACS coding scheme. Four phases of the group’s work were identified, and Markov-transition diagrams of the content were created. The overall patterns of tool use, for all members of the group, were plotted and the relationships between tool use and idea development were investigated. Two cases of different patterns of tool use were identified and these were analysed according to the practice of sketching identified in other fields of design.

Overview of findings

Learning by design:

By tracking the development of ideas as they related to the final design, and visualizing this development over time, we found that students’ interactions, both with each other and with design tools, were essential to their progression through the design process. This led to the identification of naturally occurring phases in the group’s collaborative design work, as well as indicators of movement into and out of these phases. This identification provided valuable information on the management of time and materials which, as identified in other projects, can be a challenge.

The facilitator was an important element in this system; in particular the way he used goal-oriented questions. He was able to connect the students’ activity to the task at hand. Over the course of the collaboration (40 minutes) students developed expertise, and adopted specific (and self-assigned) roles within the group. Once these roles had been established, they were adhered to and all students played important parts in the development of ideas; they demonstrated this by their collaborative actions at the white-wall. The ownership of ideas was important, as was the requirement for a permanent record of those ideas to be made.
Learning outcomes

Identifying measures of learning outcomes in these design situations can be challenging; however, the students were observed to be able to articulate an understanding of some (and often challenging) ideas about systems. One measure of the success of this group was the organic nature of its ‘designerly’ behaviour. Individual members of the group were able to return to ideas raised earlier in the design work; the group was then able to revisit these ideas and build new ideas on a new, common understanding of the design.

Implicit knowledge about the inputs and outputs from the ecosystem (under consideration in the design activity), likely impacts, and links between elements of the ecosystem was present in the development of the group’s ideas. Knowledge about the ecosystem was present in their discourse, and also in their drawings, throughout the collaborative task. This one finding reinforces the importance of analysing the data set as a whole rather than regarding separate individual elements (such as analysing audio conversations disconnected from visual imagery).

Students were all in agreement that the ecosystem in question needed to be managed in terms of the human impact on this system, and that there should be shared use, mostly in terms of urbanization (most familiar to these students) rather than in terms of agriculture or industry. They put themselves in the pictures that they drew of the creek and a strong personal connection between the creek and the group members was observed. However, there was no demonstration of an understanding of the global/local relationship in the ecosystem, nor specific reference to possible impacts of decreased water quality.

Tool use

The students, in this group, were able to use the tools in complex patterns and, within the group, they were able to specialize the tool use in terms of the roles they were playing. The importance of the multiple tools use became apparent during data analysis. While it appeared, when the data was first analysed, as if there were only minimal discussions about the creek, it became clear that all the information about the creek was being written on the wall and recorded on the tablet computer. Keeping track of multiple tools being used simultaneously by a group of students can be a challenge. We used multiple recording techniques to gain an understanding of the tool use and the tool/student interactions. During their collaborative design task, the students were effectively supported by the tools and the use of those tools was key to the students’ idea development and record keeping. The tools allowed collaboration to occur as individual ideas were articulated on the white-wall and combined in the more permanent record keeping of the tablet computer. Despite the fact that the students, for most of the session, worked collaboratively (and on-task) the social interactions appeared to interrupt the regular pattern of idea development.

Methods for analyzing the processes of learning

By visualizing the overall patterns of collaboration, we were able to identify phases in the design work that corresponded to recognizable patterns in the discourse. This led to multimodal analysis, which provided insights into relationships between the patterns of the content of discussion, the generation of ideas, and the phases of design work.

Conclusions

This paper represents our initial analysis of a large data set, collected over several meetings. Although the analysis of the entire data set is still in its early stages, we have already been able to gain a better understanding of how, when faced with a design task, students, teachers, and tools (both physical and digital) interact. Learning by design has been shown to be effective; promoting higher order skills such as collaboration, problem solving and creativity. Understanding the intersections of the social interactions of students, the physical and digital tools, and the development of ideas as part of a design process, is vital to the on-going design of learning by design projects. Future work will include analysing the interactions of the other groups present in the room, and tracking the development of all ideas to the final brief given to the multimedia design team.
Introduction

As part of a project funded by a local government organisation, a group of school students, across several year groups, took up the challenge to design a learning resource to be shared with other schools in their region focusing on a waterway of local significance. We observed, and guided the students as they worked through a design process, structured to help them learn about issues critical to water management in their area. Students had access to a space that included a variety of tools that they could use for their design work. Many aspects of design processes are important to learning and as yet, have not been discussed in the research literature.

This paper begins with a brief overview of the existing research in the field of learning by design and the processes of learning. We will then describe learning by design, and then the importance, in other fields, of sketching during the design process. We will present data that describes the integrated, and specialized way in which students used and appropriated the tools for their purposes. In our analysis we study one group during a forty-minute session. Their task was to develop their ideas about what to design. After a break they were expected to present their idea to the other groups.

As we ask learners to engage in more complex tasks, the ability to capture the processes of learning is increasingly challenging. In this paper, attention is given to the way in which the design progressed during this session with particular reference to the initial development of ideas, the use and reuse of ideas, the way the task, topic, tools, and social interactions were communicated during verbal exchanges, and the role of the facilitator in the process. In addition, initial research into the combination of tools used is presented. We bring together work on combinations of tool use in the processes of learning from online environments, with the importance of sketching in other areas of design, in order to identify patterns of productive activity in learning by design tasks. The implications of these in-depth analyses are discussed in terms of what is known about the processes of learning during a design task.

Literature Review

Learning by Design

Learning by design (LBD) is the blending of what is known about case-based reasoning, with what is known about problem-based learning, resulting in a project-based inquiry approach to science learning (Kolodner et al., 2003). A case is described as a “contextualized piece of knowledge representing an experience that teaches a lesson fundamental to achieving the goals of the reasoner” (Bergmann, Kolodner, & Plaza, 2006, p. 209). LBD leverages what is known about promoting deep and effective learning by situating it in activity that is both purposeful and engaging. Engaging learners in the process of ‘design’, facilitates their movement between evaluation and creation. Designing presents an opportunity for deep learning to occur because student-designers are required to use their knowledge of natural systems to build an artificial working replica of a functional system (Hmelo, Holton, & Kolodner, 2000). In order to complete the task the designer needs to: (1) select an approach, (2) understand nuances in function and behaviour, (3) sequence and interrelate multiple functions, and (4) evaluate compliance of functional requirements. The process of building a working replica, rather than an ‘appearance-model’, presents the learner with a project that will inevitably require multiple iterations. Within each iteration, the learner is presented with an opportunity for reflection on the current levels of fidelity, which will require revisiting their knowledge of the natural system. Linn (1996) describes how navigating between the model as studied and the model as currently under construction helps build an ever more sophisticated understanding of the system being studied.

Vattam and Kolodner (2008) describe LBD as internally driven by a “need to know” and a “need to do”. During this iterative process students share experiences and ideas as they articulate what they will need to learn in order to successfully complete the design challenge. Numerous LBD studies have illustrated positive learning outcomes for students (Bamberger, et al., 2010; Fortus, et al., 2004; Hmelo, Holton, & Kolodner, 2000; Sadler, Coyle, & Schwartz, 2000), and the role of supporting these projects with paper-based reflective journals and computer based scaffolding (Domeshek & Kolodner, 1994; Guzdial, 1998; Kolodner et al., 2003; Puntambekar & Goldstein, 2007; Puntambekar & Hubscher, 2005; Puntambekar &
Kolodner, 2005; Vattam & Kolodner, 2008). Bamberger, et al. (2010) reveal that students who engaged in LBD tasks were better able to understand scientific content, and, in particular, scientific systems. In investigating the role of the teacher in LBD tasks, Puntambekar & Stylianou, (2007) highlight the need for students to make connections between the design activity and the learning. They found this to be evident in classrooms where teachers helped students to connect prior learning to the topic being studied and where they aided in the generation of goal-related questions. Despite positive gains across a number of areas, Vattam and Kolodner (2008) identify two significant challenges to the implementation of design-based science learning (DBSL): (1) the need to bridge the design-science gap, and (2) finding a way to manage time and material constraints. They investigate software solutions that integrate explanation-construction scaffolding with modeling and simulation, and conclude that their strategy enhanced collaborative understanding and social construction of knowledge in DBSL environments.

Design activity has been demonstrated to facilitate deep learning about complex systems (Hmelo, Holton, & Kolodner, 2000; Kolodner et al., 2003). The goal-orientation of DBSL (design based science learning), where the content is fundamental to producing a working artifact, acts to contextualize the process of inquiry. “Design is used as a vehicle through which scientific knowledge is constructed and real-world problem-solving skills are cultivated. The design challenge provides impetus for identifying what needs to be learned and for sustaining engagement in inquiry over time, as well as providing need for cultivating and using a variety of skills.” (Vattam & Kolodner, 2008, p. 407). Vattam and Kolodner (2008) describe LBD as internally driven by a “need to know” and a “need to do”. During this iterative process students share experiences and ideas as they articulate what they will need to learn in order to successfully complete the design challenge. In describing this process they highlight the importance of the design rule of thumb – which assist learners to connect content and application.

The early conceptual phase of design is cognitively very demanding. During this phase, ideas are generated rapidly. Designers need to try out new ideas quickly and cheaply before committing to one for further development (McGown, Green, & Rodgers, 1998). During this process, the intentions of the designers are represented, or externalised, in the form of verbal explanations, written documents, sketches, drawings, diagrams, and sometimes as models. Free-hand sketches are an indispensable tool at this stage not only for externalising design ideas in order to communicate with others, but also for examining the potential of a solution before further commitment. For designers, drawing is the act of exploration (Hokanson, 2008), discovery (Berger, 2007), and an aid to their thought process (Buxton, 2007). Designers draw in order to spot problems, see new features and relations among elements, discover or promote new ideas and refine current ones (Suwa & Tversky, 2002).

The importance of sketching in design is not the sketch as a final product of design, but as a process that explores, questions, suggests, proposes, and provokes thoughts and ideas (Buxton, 2007). In other words, “sketching is thinking” (Goldschmidt, 1991, p. 130). This process enables the designer to find new aspects of the problem and to generate new ideas (Suwa, Gero, & Purcell, 2000). Designers from various fields rely on the use of visual representations as thinking tools in their design process. For example, Henderson (1999) quotes an engineer who stated “I can’t think without my drawing board”. Sketches can greatly improve communication in collaborative team situations (Eppler & Burkhard, 2006); they can be used to assist the group reflection and communication process. This is because sketches and drawings bring the main features of the object of design to the conversation by making them explicit and thus debatable.

The processes of learning

Visualising and analyzing the processes of learning is a relatively new area in the learning sciences. Reimann’s (2009) seminal work outlines the importance of time and order in considering the processes of learning. Generally, work in this field has concentrated on decision-making (Reimann et al., 2009; Kapur, 2011), and has used a variety of methods of analysis, such as heuristics mining (Reimann et al., 2009), first-order Markov models (e.g. Thompson & Kelly, 2012), and hidden Markov models (e.g. Southavilay, Yacef, & Calvo, 2010). For a review of this, see Goodyear, Jones & Thompson (forthcoming). In this study, we examine the processes of design in a learning context, with a focus on the development of ideas, as well as the content of the discourse (Kennedy-Clark & Thompson, accepted), and the processes involved with the tools used in a dedicated design space. Other work done by our group (Thompson, Ashe, Carvalho,
Goodyear, Kelly & Parisio, accepted) has identified emergent group processes associated with expertise and group work over longer periods of collaboration.

Much of the work examining the processes of learning during complex collaboration with regard to combinations of tool use, has been performed in online spaces (see for example Zenios & Holmes, 2010; Thompson & Kelly, 2012a; 2012b). These studies have examined the affordances of using a combination of online tools for discussion and idea development (such as chat or video conferencing tools), for the permanent recording of the progress of the group, and for in-depth investigation of a problem (such as wikis). In these studies, the permanence of the recording space (the wiki) was important for the progression of the collaboration; more complex discussions were able to take place once ideas were recorded. The recordings enabled participants to refer back to previous ideas. In work on face-to-face collaboration, Thompson et al. (accepted) have shown that differentiated tool use can be an indicator of successful collaboration in a group, as students develop expertise in the role and tasks related to the tool used.

This study

In our study, the focus of the design is an online educational resource about a local waterway (the creek). Generally, systems are characterised as having components or definable elements, interactions or interrelations between them, and in open systems such as ecological systems, fluxes in and out of the system boundaries (Reimann & Thompson, 2009). Students needed to consider all these components in their understanding of the creek and the surrounding environment. Systems also often behave in a dynamic manner over time (Limburg, O'Neill, Costanza, & Farber, 2002; Ossimitz, 1997). Another characteristic of complex systems is emergence, where aggregate level structures affect the behaviour of the elements of which they are composed (Wilensky & Reisman, 2006). Many people have trouble understanding complex systems even when they are illustrated using tools such as models. It was hypothesized that a learning by design project, where the design task was to create an educational resource, may result in a greater understanding of the connections between elements of the system, as well as changes over time and emergent features of the system.

Methods

A group of 16 students participated in the project funded by a regional organization of councils, supported by their high-school and a local environmental rehabilitation organization (an additional 11 adults). The aim of the project was to provide students with an innovative fieldwork and multimedia framework for engaging other students in water and land management issues. The project involved students gaining an understanding of water in their environment and centred on a local waterway (the creek). The name of the creek in focus is South Creek; it has been described as the most degraded in the region. Risks to the creek include vegetation clearance, urbanization, and agriculture; issues such as increased nutrient levels and weed species in riparian zones are also of importance. Students and stakeholders participated in a multidisciplinary design process, over several months, in order to produce a learning resource or framework, to be promoted for use in schools across the region. The students participated in planning sessions, a site visit, and a day of hands-on site restoration at the creek, before attending a design day at the University of Sydney. The day in at the University was an opportunity for them to concentrate on, and develop their ideas related to the educational resource to be created, propose possible formats, identify constraints and generate a consensus upon which a brief for the multimedia designer could be written.

The participants taking part in the design day at the University comprised a multidisciplinary team. As well as the school students (who ranged in ages from 12 to 17 years), there were experts from various fields, such as education, environmental science and web/app design. The day started with each represented discipline outlining their desires and constraints for the design of the proposed educational resource. These starting parameters were summarised and used during the main design part of the day. In the multimedia design space (the Design Studio), participants were led through the first three stages of a design process: Empathize, Define, and Ideate (following the Stanford University Institute of Design – An Introduction to
Design Thinking\(^1\)). The *empathize* stage took the form of a whole group brainstorming activity during which the desires and constraints, outlined earlier, were discussed and the critical components extracted. Participants worked in pairs for the *define* stage; each dyad performed a needs analysis to help define the resource. For the third stage, the *ideate* stage, the participants worked in groups according to discipline area. One group contained all the adults including educationalists, web/app designers and environmental scientists. The other three groups comprised five to six students. During the *ideate* stage, participants were asked to generate ideas. They were asked not to limit their ideas to their knowledge of technology but to record all ideas. The intention was to explore a wide solution space so that later in the day the ideas could be distilled into one coherent solution, to be presented to the web/app development team as a design brief for the creation of a resource prototype.

This paper follows one of these student groups during the *ideate* stage of the design day. There were five members of the group, three females and two males, whose age ranged from 12 to 16. The other person who was key in this group was the facilitator, who was asked to keep the groups moving towards to their goal of coming up with ideas that would feed into the greater design. We have given the participants pseudonyms. We recorded their interactions with both the physical tools (whiteboard/pens/erasers) and digital tools (iPad and projected screen). We collected video of the group interacting, two members of the group wore audio recorders, and photographs were taken every 12 seconds of the whiteboard on which students were working. Students in the group were given a choice regarding the digital tool that they could use (computer, electronic whiteboard, or iPad). Students in this group chose to use an iPad which was projected onto a wall painted in whiteboard paint (a ‘white-wall’ see Figure 1). The transcription of their discourse was analysed in order to identify ideas important in the development of their design. These were then discussed, and agreed upon by all authors of the paper in a group meeting. The Collaborative Process Analysis Coding Scheme (CPACS) was used to code the transcript (for a full description of the coding scheme, see Kennedy-Clark & Thompson, accepted; only the macro-level code, *Content*, was used in this analysis). Initial agreement between raters was 52%, after discussion 96% agreement was achieved. The *Content* code has shown that a periodic oscillation between phatics, tool use, planning, topic, task, and off-task. Other work using the *Content* code has shown that a periodic oscillation between phatics, tool use, planning, topic, task, with all elements included, is indicative of successful collaborative work. This tends to correlate with observable patterns in other macro-level processes, such as decision-making (Kennedy-Clark & Thompson, accepted). The generation of Markov transition probabilities has been shown to be a useful tool to visualize the patterns of content in discourse, and will be used in the analysis presented here. Markov transition diagrams illustrate show the probability of each state transition

\(^1\)Retrieved from: https://dschool.stanford.edu
(for example, from topic to task), and are appropriate for processes in which there is an expected order of states.

Using the video we made a record of the tool use, for each member of the group, in 30 second intervals. The tool used, whether participants were writing or erasing, and whether they were writing inside or outside the projected area of the iPad were all recorded. As a group, we analysed the transcript of the discourse, and determined the main ideas that related to the development of the design. We analysed the images taken of the whiteboard every 12 seconds, and for each, determined what area of content they related to, according to the CPACS Content code (see Kennedy-Clark & Thompson, accepted, for more detail). The Content code includes phatics (social interactions), tools (reference to the tools, physical and digital, in the learning environment), planning (about the task and the group processes), topic (in this case the creek, what the game is about) and the task (the design work). The images were coded by one researcher, and half of the images coded by a second rater. Inter-rater reliability of 55% was achieved in the first instance, and 86% after further discussion. The ideas were then plotted, over time, in combination with the tools used by each person and taking into account the content to which they were contributing. We used this visualization to determine patterns of tool use, and analysed the images taken of the whiteboard from the perspective of sketching practices of designers from other fields.

Analysis of the phases of design: Following idea development and patterns of collaborative discussion

The ideas that were considered to be important to the development of the group’s design were identified in the transcripts of the discourse. Selection was based on key descriptors of the end product rather than ideas about how to implement the design or references to games the students used as inspiration for their offering. They are presented in Table 1, below.

Table 1: Idea development

<table>
<thead>
<tr>
<th>Idea</th>
<th>Description</th>
<th>Proposed by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Original illustration</td>
<td>Sue (Mark)</td>
</tr>
<tr>
<td>2</td>
<td>A computer game</td>
<td>Sue</td>
</tr>
<tr>
<td>3</td>
<td>Access to technology</td>
<td>Steve</td>
</tr>
<tr>
<td>4</td>
<td>“taking care of”</td>
<td>Philip</td>
</tr>
<tr>
<td>5</td>
<td>Managing</td>
<td>Philip</td>
</tr>
<tr>
<td>6</td>
<td>The Creek</td>
<td>Philip</td>
</tr>
<tr>
<td>7</td>
<td>“challenge others”</td>
<td>Steve/Mark</td>
</tr>
<tr>
<td>8</td>
<td>Levels of difficulty</td>
<td>Steve/Anna</td>
</tr>
<tr>
<td>9</td>
<td>“a player in the game”</td>
<td>Anna/Steve</td>
</tr>
<tr>
<td>10</td>
<td>Gaming platforms</td>
<td>Mark</td>
</tr>
<tr>
<td>11</td>
<td>Different game “views”</td>
<td>Beth</td>
</tr>
<tr>
<td>12</td>
<td>Role playing</td>
<td>Mark</td>
</tr>
<tr>
<td>13</td>
<td>Violence</td>
<td>Philip</td>
</tr>
<tr>
<td>14</td>
<td>Score, points and awards</td>
<td>Anna</td>
</tr>
<tr>
<td>15</td>
<td>School subject and class</td>
<td>Steve</td>
</tr>
</tbody>
</table>

There were 15 important ideas that were directly relevant to the development of the group’s design. The number also infers the order in which the ideas were suggested. Not all ideas moved the group forward in their design in the same way. For example, three of the ideas (taking care of, managing, the Creek) occurred in quick succession, by the same person (Philip), and are closely related to each other. Violence, however, was less related to the ideas around it, and could almost be considered tangential. It is possible that this was an idea stimulated by the discussion taking place in one of the other groups. There are many ways in which the ideas could be rated (or classified) however, for the purposes of this analysis, all have been assumed to be of equal importance to the final design. Table 1 also shows the name of the group member who first suggested the idea. Steve, the facilitator, played an important role in suggesting ideas at key points during the design process, in particular co-suggesting ideas, helping the students to recognize the contribution of all ideas to the final product, and following the process of design.
Reporting the counts of content codes for each person, or for each idea, adds little to the understanding of the design process. Instead, the content codes were plotted over time, for each participant (all four students and the facilitator), taking the generation of ideas into account. This is presented in Figure 2.

Figure 2 shows the development of ideas in the process of design, for each member of the group, and also the process of discussion of content. Time (from 0 to 41 minutes) is shown on the x-axis, and each new idea (see Table 1) corresponds to the number on the y-axis. Where an idea is built on, or developed, the preceding codes are only repeated if the reference clearly takes the conversation back to an earlier idea. We chose to do this for two reasons. First, the notion of design assumes a cumulative and revised whole, and second it was those moments, where iterations emerged, that we examined more closely, and discuss below. Each person has been given a different colour. Circles are the utterances which include reference to a specific idea, and diamonds are the utterances that have been coded with content. Each content code was given a numerical value: phatics – x.1, tool use – x.3, planning – x.5, topic – x.7, and task x.9. For example, at about 12 minutes, participants had generated ideas to number 4 (“taking care of”), and the subsequent discussion revolved around the task, and the tool: Sue was active in this discussion. At about this time, she also mentioned an earlier idea, idea 1 (the original drawing), however subsequent discussion by the rest of the group was related to the idea of “taking care of” the environment, specifically the creek. In order to explain the patterns observed in Figure 2, the video of the collaboration was analysed.

The collaborative design work analysed here opens with a longer period of discussion, following on from the initial idea. This consists of activity and conversation that seeks to organise and orientate the group in terms of physical space, available tools and the task at hand. It includes discussion about location and centers on an illustration drawn by Sue and Mark before the official ‘start’ of the group work. Sue starts by making use of the visual representation of their efforts thus far, she uses words economically but, from the beginning, her presence can be seen in how she records ideas and scaffolds the group’s thinking. There are times when Sue takes ownership of ideas; however, her influence can be seen predominantly in how she maintains ownership of the tools and space in which she records ideas and how she returns the group to the objectives of the task. Anna who seems reluctant to start without adult help precipitates the second phase of the design work. It is apparent in the recordings that she is engaged at this stage of the collaboration, however the rest of the group seems not to hear her suggestions or questions. During this time, the phrase: ‘what are we supposed to do?’ is used by many members of the group. It is Anna who approaches the facilitator, Steve, and he responds with a series of questions that directs the group to value
and develop the ideas they have already had. Phrases such as: You are stealing all these ideas (which referred to the results of the earlier define stage); What are you actually designing?; There’s some ideas (pointing again to the white-wall); It’s got to be fun so what is it?; It was your must have thing that you just drew up so what does it do? (this question was asked of Sue); and What are you actually designing? Sue continues the discussion with reference to what she has drawn and following further goal-oriented questioning from Steve, says “It’s a computer game”. This moves the group to the second phase of their design.

The activity which follows includes getting familiar with the iPad and the orientation of its projected screen, allocating space within the projected iPad screen on the wall, selecting whiteboard markers and trying them out. It also includes an extended discussion about games and gaming platforms. Knowledge of, and access to, different digital devices and games stimulates discussion about the design task which leads to documentation of objectives on the white-wall. It is not until Steve returns that Philip justifies their discussions by relating it back to the project. After this, a chain of closely related ideas commenced that include taking care of the creek, and managing a game. This ‘stacking of ideas’ (seen in Figure 2 between minute 14 and minute 16) is led by Philip who suggests several ideas but seldom dominates the subsequent conversation. The rapid turn-taking in the discourse, starting with Steve at idea number 2, is carried on by the students, particularly between Philip and Mark to idea number 5. At this point, Anna, who can be seen in the video recording observing Beth, Mark and Sue sketching characters on the wall, gains Steve’s attention for feedback on their progress. Steve continues the techniques, employed earlier, of goal-oriented questioning and seeding ideas. He says: Ok, so are you yourself in this game or do you choose a character? Mark answers with: you as a character in the game and adds the notion of personal challenge.

The next observable phase in the collaborative design work can be seen in Figure 2, as idea 12 (role playing) is suggested for the first time, utterances related to the task are further apart, and there is no obvious pattern to their distribution. As the discussion returns to gaming platforms, role playing and violence, Philip says Make it a violent game. Mark objects, saying that he doesn’t like violence or violent games, and attempts to get support from other members of the group. During this time, the social interactions are important and threaten the cohesion of the group. Anna directs negative comments at Mark, and Beth attempts to distract and refocus the group by embellishing their sketched characters on the wall. This marks the end of the most productive period of idea generation, all of which occurred in a relatively short amount of time.

The final phase, during the discussion around idea 13, is marked by the failure of one of the tools. During this time, the projection of the iPad onto the white-wall ceases to work, although the iPad itself is still able to be used and the entire wall is available for writing on. At this point, members of the group seem distracted by other groups working in the same room, and physically withdraw from the space in which they had been working. Even when the iPad projection is restored, some members do not return to the shared space. Mark’s absence is clearly visible in Figure 2 from the introduction of the notion of violence into the game and after the resulting verbal exchange he withdraws from participation in idea generation. During this time he attempts to take ownership of the iPad in order to record ideas however Sue retains control. After trying to help restore the iPad projection to the wall he sits down against the wall, and draws a city near a river. Philip and Sue work on documenting objectives with some help from Beth and again it is not until Steve returns that a few more ideas are generated and a conclusion is reached.

The collaborative design process was divided into four phases, identified through in-depth analysis of the discourse in combination with the visualization of the content codes and idea generation over time. Phase 1 involved idea 1; Phase 2, ideas 2–10; Phase 3, ideas 11 and 12; and Phase 4, idea 13. In order to determine if there were discernable patterns to the discussion of content in these phases, Markov transition probabilities were calculated for each of these phases, and the diagrams can be seen in Figure 3.
Figure 3: Markov transition diagrams for the four phases of design work

Figure 3 shows four distinct patterns of discussion with regards to content, during the design task. In each, the five elements of the content codes are displayed: phatics (the social interactions), tool (reference to the physical and digital tools provided), planning, topic (anything that would be seen in the game, for example the creek, hiring workers etc), and task (utterances related to designing the game). Links between these elements are shown only if the probability is greater than 0.25, or if the number of transitions is greater than 10.

In the Phase 1 transition diagram, there is a clear emphasis on planning and the tools that would be used. Social utterances were followed by those connected to either tool use or planning. If members discussed tool use, they either continued discussing this (57% of the utterances) or moved to planning. Very little of this discussion was related to either the topic or the task to be performed. This aligns with the in-depth analysis, which identified this phase as an orientation and planning phase.

Phase 2 of the design work was described as rapid idea development. The transition diagram above shows a regular cycle through the elements of content: from planning to tool use to topic and then to task, with a return to planning. In all cases, when students begin to discuss each of these elements, they tend to focus on that element. The social interactions are not related to any one of these. This, again, supports the findings of the earlier analysis. This design work was characterized by productive discussion, with few distractions; the group members appear to be focused on their design work.

In the in-depth analysis, phase 3 was described as ending the development of ideas with a focus on both positive and negative social interactions. The phase 3 transition diagram supports this finding. The link from phatics to itself (53%) shows that group members remained in this element of the content. In addition, links from other elements to phatics (planning and task) shows that the members were distracted from the previous cycle of ideas development. The link between planning and tool use still exists, but for very small frequencies. Initial observations of the design work had led to an assumption that the failure of the iPad was the trigger for the group dispersal, however it seems that the social interactions may have preceded this.

The key event in phase 4 was the failure of the projection of the iPad. During this time constructive work ceases as the group waits. In Figure 3, the transition diagram shows that there is only one link between different elements, which is from planning to tool use, presumably indicative of problem solving related to the technical issues. This figure indicates a lack of connection between elements of the discussion, meaning that the links were distributed between so many different elements that none had a high enough probability to be displayed.
Identification of patterns of tool use and sketching practices

The design studio was equipped with a variety of design tools and participants were able to use them as they wished. This group of students was assigned to an area of the studio that had a white-wall (the entire wall set up as a whiteboard) an assortment of coloured marker pens and the ability to project either a desktop computer or a tablet computer, onto the wall (see Figure 3). They were also given blank paper and pens, sticky notes and various paper-based templates along with reference materials, which included maps and curricula resources. The students made no use of the paper-based tools; at no point did any of the group use, or even make reference to using, the paper-based resources provided. All activity revolved around the digital projection onto the white-wall; even the use of the physical marker pens were influenced by the projected image.

Figure 4 shows tool use by this group during the course of their collaboration. Each student is represented by a different colour, and each section of the graph represents a different use of a tool. Circles, at the bottom, show the use of the iPad which, apart from a brief use by Mark at approximately four minutes in to the work, was mostly used by Sue, with brief turns by other students. The next two sections refer to writing on the whiteboard, both inside and outside of the space illuminated by the iPad projection (see Figure 1). This activity is undertaken, at some point in the session, by all members of the group; there are periods of time when four of the five group members are writing on the whiteboard in the projected space simultaneously. Some work is performed outside the projected space, the most notable towards the end by Mark. Erasing is shown in the top section of Figure 4, and this shows that writing was erased from the whiteboard throughout the group-work, in particular by Mark, but all members engaged in this activity at some point.

The entire session can be broken down into five separate phases; setup, briefing, designing, technical problem with the tablet, and finally continuing with the design task. Initially, one of the students in this group, Sue, requested that the desktop computer (which was operated via a wireless keyboard and mouse) be projected onto the white-wall; she indicated that she thought the task would be simpler with a desktop
system rather than a touch tablet computer. Sue took control of the computer keyboard in anticipation that the group would accept her request. Despite this, the rest of the group elected for the tablet computer to be projected and Sue relinquished control of the computer to Mark. It was not long before Sue took control again, asking Mark to hand her the tablet, which he did. During setup and briefing, the tablet was not used significantly; it was mostly used during the two design phases. In both of these phases Sue was, by far, the dominant user of the tablet computer. In the entire session, there were only 2 minutes of the design work where Sue relinquished the tablet computer; during this time she was actively writing on the white-wall.

The students recorded their ideas by writing and drawing with both the physical marker pens and the digital pens on the tablet computer. These physical and digital tools were used in combination. Even though the entire wall was available for use as a whiteboard, the students mainly confined their design work to an area formed by the projection of the tablet computer. As this space was relatively small, it became necessary to keep a record of what was physically written on the wall before erasing to make more space. In order to achieve this, Sue copied the written text onto the tablet computer, hence making a permanent digital record of the writing. This text could then be brought back onto the wall, from the tablet computer, after the original had been erased. By taking control of the tablet computer, Sue effectively controlled the pace of the design task and also had a certain amount of autonomy over which sections of the written text were preserved in digital form.

At various times, one or more students broke away from the accepted practice of writing within the projected area to build up an independent section on the white-wall. This could be regarded as a prototyping area, a place to sort out ideas before committing them to the projected area (and hence into the tablet computer), or as a method of rebelling against the group with ideas that had not been accepted by the group as a fruitful way forward.

Sue was a very active member of the group. Once the activity was underway, she took control of the tablet computer and dominated the digital artefact creation. There were two points, in the session, when Sue relinquished the tablet computer; one was when she became very active writing on the white-wall, effectively controlling the wall space, and the other was when the tablet computer had a technical fault. Sue stopped using the device as it was no longer being projected onto the white-wall. Despite not using the tablet computer, Sue still held on to the device, only releasing it for technical assistance.

The use of the tool in relation to the development of ideas was then plotted. As outlined in the methods section, the whole group decided on the ideas that were relevant to the development of the design. Each image was also coded to illustrate any contributions the students made to the development of the content. These are shown in Figure 5. The development of ideas, identified in the discourse (the larger circles), with each individual idea represented by a horizontal line. Images of the whiteboard were coded for the content of what was drawn, written and displayed. The content codes were phatics (x.1), tools (x.3), planning (x.5), topic (x.7) and task (x.9). Each person is represented by a different colour, in addition to the five members shown in Figure 4, Steve, the facilitator, is included.
Figure 5: Additions made by participants during idea development, according to the content added over time

Figure 5 shows that the design process was not linear, that there were a number of points when participants returned to earlier ideas and gave them more attention. For the most part, the whiteboard was used for recording information about the task and the topic, rather than for planning, for phatics, or for further reference to the tools. Often, the iPad is used just before a new idea is suggested; this could be because participants were waiting for information to be recorded in order to move on. There are two occasions that were chosen for indepth analysis of sketching practices due to the distinct patterns in participants’ use of the tools. The first, collaboration, occurs from 18 minutes to 23 minutes, when students simultaneously write on the whiteboard while the iPad is also being used. It is at this point that they return to the ideas that were generated earlier in the discourse. The second, specialization, occurs from 31 minutes to 37 minutes, when two members of the group dominate the use of two of the tools, for different purposes (Sue, on the iPad, focuses on the task, and Mark, on the whiteboard, focuses on the topic). These two patterns are discussed below.
This *collaboration* analysis involved studying 30 images, taken 12 seconds apart (images 4248-4277). The students, in this instance (shown in Figure 3), are collaborating to produce the ‘objectives’ for their idea of a game. It is notable that the students demonstrate behaviour similar to practicing designers in many design fields. For example, the students use a variety of ways, using the available tools, to communicate their ideas to the other members of the team. Their verbal expressions are supported by drawings and text on the whiteboard. This is similar to ‘talking sketches’ produced in the early stages of engineering design where ideas are exchanged and negotiated using sketches, text and diagrams (Ferguson, 1992). Visual representations, such as these drawings and marks on the whiteboard, hold the design ideas stable so they can be argued and negotiated.

During this session, students made several types of marks on the whiteboard. There is a bulleted list of possible platforms for the game, such as computer, iPad, and Xbox. Some of the main ideas are written in capitals and enclosed by irregular shapes. Important terms and headings are underlined for emphasis. Groups of ideas, such as similar device types, are bracketed to illustrate similarities and relationships. At one point, lines were drawn across the bottom of the screen, projected on the wall, to symbolise the creek.

At this initial stage, ideas were still developing as they were being negotiated; some ideas were further developed and some were erased and replaced by new versions. For example, at one stage, Phillip adds (and underlines) the words ‘get funds’ on the whiteboard. Beth develops the idea by adding ‘selling lemonade’ underneath. Phillip realises that Beth has misunderstood the idea and continues with his line by adding ‘off entrepreneurs’. The vagueness of the ideas and words on the whiteboard does not seem to be an issue of concern for the students. In fact, it stimulates the conversation as the students try to make sense of the design task. This is a typical situation in most design fields where visual representations of ideas are initially vague and cannot be fully explained but become clearer as the designers’ thoughts progress (Hansen, 2000). The drawings and text on the whiteboard seems to have a fluid status. These represent ideas that are still changing. Sue is in control of the iPad and once an idea is relatively crystallised she commits the idea to digital ink, thereby giving the idea more permanence. After Sue copies the ideas onto the iPad, the other team members do not mind erasing the text on the whiteboard wall.

Another similarity with typical design practices, that this session demonstrates, is that drawings and marks on the whiteboard can be considered as either individually owned or as a shared entity (Eppler, 2007). For example, at one stage Anna decides to write her objectives for the game on the board by commandeering one section of the available space and drawing a line around it (see the lower, centre area of the projected image in Figure 3). She makes sure that the other students know that these are her ideas and they are not to be changed or erased. This is an example of individual ownership of a visual representation. The rest of the representations on the whiteboard are mostly shared where anyone can add to them; no one has declared their ownership.

This instance also shows how design representation can take both physical and digital formats (Eppler, 2007). This is clearly seen by observing how Sue records the team’s ideas using the iPad, which is projected onto the wall, while the rest of the team draw and write on the whiteboard wall with physical pens. The interplay between these two tools, the iPad and the whiteboard wall, is worth noting. All of the team members are at once able to see the wall and what is being added to the iPad. They often comment on the text added to the iPad and even suggest more additions to the perceived permanent, master version residing on the iPad.
Later in the session, the design needed to be finalised and a set of objectives put in place. This specialization session was analysed using 25 images, each taken 12 seconds apart (4334-4359). At this stage (shown in Figure 4), ideas and representations on the whiteboard wall were slowly erased as they were stored on the iPad. The idea of permanence given to the digital form is very obvious here as the previously individually owned, and fiercely contested ideas on the wall, are erased and replaced by the compiled list on the iPad. For example, Beth tried hard to protect her ideas written on the wall throughout the session. At one stage she proclaimed “don't rub out my ideas”. Nevertheless, after Sue copied her ideas onto the iPad, Beth took the eraser and wiped the text from the whiteboard herself. This is typical in most design areas where the initial sketches and representations are disposed of in favour of more formal representation of the design, often expressed in textual format (McGown, Green, & Rodgers, 1998).

While this sorting and storing stage was underway, another event happened; Mark started drawing on the whiteboard wall away from the collaborative area. Mark’s drawings did not appear to be intended for sharing with the team since they were drawn outside of the screen area illuminated by the iPad projection. Mark was visualising the previous ideas that he shared on the whiteboard wall under the heading ‘Objectives’. These ideas were about “trying to keep your part of the creek clean while urbanising around it”. Mark visualised this idea by drawing a creek in blue pen with roads surrounding it in black pen. He also drew high-rise buildings in red and added grass areas in green. Mark did not share or discuss his drawings with anyone else. This seems to be an example of a ‘thinking sketch’ (Ferguson, 1992). Thinking sketches are often drawn by designers in order to better understand a situation and to develop personal ideas. Mark appears to be drawing for a similar purpose; he used the whiteboard, away from the projected screen, because the drawing was not meant to be a permanent record; it was not intended for sharing with the team members.

Discussion and Conclusions

The aim of this paper was to describe the processes of design and patterns of tool use observed in a group of five students during a learning by design project. Multimodal analysis has provided insights into relationships between the patterns of the content of discussion, the generation of ideas, the phases of design work, and the roles of the tools used. The findings will be discussed in terms of their relationship to learning by design, learning outcomes, tool use, and methods of analyzing group processes.

Learning by Design

Steve, the facilitator, was an important element in this system; his goal-oriented questions (Puntambekar & Stylianou, 2007) provided students with the opportunity to navigate between the design studied and that
under construction (Linn, 1996). Opportunities for reflection were incorporated into the productive phase of ideas generation without disturbing the generation of new ideas. Steve’s role in connecting their activity to the task at hand, and his persistent use of goal-directed questioning, is clearly instrumental in aiding this group develop their ideas over time. Their freedom to access and talk about gaming systems, with which they were already familiar, and the ease with which they could record, draw and build upon prior iterations (all with the express aim of designing a tool to connect other students with the project) was well supported in this environment.

**Learning Outcomes**

The aim of this paper was to describe the processes of design evident in the interactions between group members and the tools provided in a learning by design project. We have shown that students were able to articulate an understanding of some (and often challenging) ideas about systems. In addition we were able to track the development of ideas as they related to the final design, and visualize this development over time. By visualizing the overall patterns of collaboration, we were able to identify phases in the design work that corresponded to recognizable patterns in the discourse. Social processes and interactions with tools were essential to the progression through the design process. The management of time and materials was identified as a challenge of learning by design projects (Vattam and Kolodner, 2008). Part of the challenge is knowing when to intervene in a group’s collaborative design work. Identifying naturally occurring phases, and the indicators of movement into and out of these phases is essential to managing this process.

The learning outcomes for students participating in this project concerned knowledge about water quality issues as well as an understanding of the process of design for learning. In the analysis presented, the focus has been on the social interactions and interactions with both physical and digital tools. However, the ideas concerned with managing the creek occurred early in the design work, and when students returned to these ideas, they added to them, rather than revising them. Implicit knowledge about the inputs and outputs from the ecosystem, impacts, and links between elements of the ecosystem was present in the development of their ideas. Knowledge about the ecosystem was present in their discourse, and in their drawings, throughout the collaborative task. Students were all in agreement that the ecosystem in question needed to be managed in terms of the human impact on this system, and that there should be shared use; mostly in terms of urbanization (most familiar to these students) rather than in terms of agriculture or industry. They did put themselves in the pictures that they drew of the creek, and a strong personal connection between the creek and the group members was observed. There was no demonstration of an understanding of the global/local relationship in the ecosystem, nor specific reference to what the impacts of decreased water quality might be.

One measure of the success of this group was the organic nature of its designerly behaviour. While we concentrated only on the idea generation stage of design in this analysis, Figure 2 showed that this group returned to ideas raised earlier in the design work. An important feature of the group’s design process was the way in which the participants revisited earlier ideas. This was done naturally, within the processes of conversation, and new ideas were built on the new, common understanding of the design.

**Tool use**

Students’ use of tools was a key part of their idea development and record keeping. The tools available in the dedicated design space effectively supported the collaborative design work of the members of the group. The tools were a key part of all the elements of discussion, including the productive design work (see Figure 3). They allowed collaboration to occur as individual ideas were articulated on the white-wall and combined in the more permanent record keeping of the iPad. However, it was the social interactions that seemed to interrupt the regular pattern of idea development (as seen in the Markov diagrams).

The collection of multiple streams of data allowed a detailed, multimodal analysis of the processes of collaboration to be reported in this paper. Visualisations of tool use, and design processes over time allowed the recognition of patterns, and directed the in-depth analysis of sketching practices of students to be carried out. Students used the tools available to them in complex ways and for different purposes – they used the white-wall for ideas development and the iPad for recording in a more permanent way. The iPad became central to their collaboration. We can see that when it failed, the group also ceased writing on the
white-wall. Perhaps without the permanent record created, they were reluctant to move on, despite the availability of the whole wall for writing on. Over the course of the collaboration (40 minutes) students developed expertise, and adopted specific roles within the group. This was seen most clearly with Sue and Mark. Only one person could control the iPad at any one time; multiple people could use the white-wall simultaneously. Figure 5 shows significant overlap at the wall, with multiple people contributing to the task. This may indicate that the task was indeed collaborative in nature and that the use of the tablet computer was more pragmatic (someone had to keep records of the generated ideas) than an attempt to control the design task. All students were key in the development of ideas, demonstrated in their collaborative activity at the white-wall. The ownership of ideas was important, as was the requirement for a permanent record of them to exist.

**Methods of analyzing group processes**

By applying methods of process analysis to this data, phases of idea generation as well as patterns of discourse were identified. Future research will apply these to the analysis of the other three groups that participated in the project. Furthermore, comparisons between the groups will be made using lag sequential analysis techniques. It is expected that the orientation phase would be common across all groups. One question to investigate is what moves the group from the orientation phase into design work. In this case, it appears that the facilitator played a significant role. Given that he visited all groups, it will be appropriate to investigate whether he played a similar role and prompted entry into this phase in all cases. A larger question for this research is what role the interaction between the task, the social interactions, and the coordination of tool use play in influencing the processes of learning.

This paper represents our initial analysis of a large data set, collected over several meetings. Future work will include adding the other groups present in the room to the analysis, and tracking the development of their ideas to the final brief given to the multimedia designer. Understanding behaviour associated with the intersection of the social interactions of students, the physical and digital tools, and the development of ideas as part of the design process is vital to the design of learning by design projects in the future.

**References**


