Phases of design: Following idea development and patterns of collaborative discussion in a *learning by design* project

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Abstract: Learning by design (LBD) has a long association with learning about complex environmental systems. This investigation traces the development of ideas within a group of five students engaged in a collaborative design process. Tasked with the design of an online educational resource, about a waterway of local significance, this group was one of three for which multiple streams of data (audio and video) were collected. Ideas central to the progression of their design were identified and represented visually over time, showing the impact of each group member and the facilitator, and discourse was coded according to the content code of the CPACS scheme. Four phases of design were identified and Markov-transition diagrams of the content were interrogated. This paper makes a contribution to our knowledge of the phases of design evident during LBD tasks, which could have implications for the design and management of such projects in the future.

Introduction

Engaging school students in tasks that support collaboration, technology enhanced learning, and the understanding of complex systems is challenging. As part of a project funded by a local government organization, a group of school students engaged in the design of a learning resource to be shared with other schools in their region. The group included 16 students across multiple year groups and the focus of the project was a waterway of local significance. The students were observed and guided as they worked through a design process structured to help them learn about issues critical to water management in their area. This paper begins with a brief overview of the existing research in the field of *learning by design* (LBD) and the processes of learning about complex systems. The analysis examines one group of students during a forty-minute session. Their task was to develop ideas about their design in order to present the design concept to the group as a whole. Attention is given to the way in which the design progressed during this session with a focus on 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. The implications of this in-depth analysis are discussed in terms of what is known about the processes of learning during a design task.

Literature Review

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. Involving 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 behavior, (3) sequence and interrelate multiple functions, and (4) evaluate compliance with 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. With each iteration the learner is presented with an opportunity for reflection on current levels of fidelity requiring them to revisit 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, Cahill, Hagerty, Short & Krajcik, 2010; Fortus, Dershimer, Krajcik, Marx & Mamlok-Naaman, 2004; Hmelo, Holton, & Kolodner, 2000; Sadler, Coyle, & Schwartz, 2000), and the role of providing support for 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). 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, both of which were evident in classrooms where teachers helped students to connect prior learning to the topic studied, and where they assisted students 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. In a more recent study Bamberger, et al. (2010) reveal that students who engaged in LBD tasks were better able to understand scientific content and, in particular, the workings of scientific systems.

Generally, systems are characterized as having components or definable elements, interactions or interrelations between the elements; and in open systems such as ecological systems, fluxes across the system boundaries (Reimann & Thompson, 2009). To understand the local creek and its surrounding environment, students in this study needed to consider all of the components of the system as well as the fact that the system may change over time (Limburg, O'Neill, Costanza, & Farber, 2002; Ossimitz, 1997). Another characteristic of complex systems is emergence, where aggregate level structures affect the behavior of the elements of which they are composed (Wilensky & Reisman, 2006). Many learners have trouble understanding complex systems even when they are illustrated using tools such as models. It was hypothesized that a *learning by design* project, in which 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.

Visualizing 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, Frerejean & Thompson, 2009; Kapur, 2011), and has used a variety of methods of analysis, such as heuristics mining (Reimann et al., 2009), first-order Markov models (Thompson & Kelly, 2012), and hidden Markov models (Southavilay, Yacef, & Calvo, 2010). In this study, we examine the processes of *design* in a learning context, with a focus on the development of ideas and the content of the discourse (using Kennedy-Clark & Thompson's CPACS (accepted).

Methods

A group of 16 students and 11 adults participated in the project funded by a regional organization of councils, and supported by their high-school and a local environmental rehabilitation organization. The aim of the project was to develop an innovative fieldwork and multimedia framework to engage other students in water and land management issues. South Creek, the focus of the project has been described as the most degraded creek in the region. Threats to its health include vegetation clearance, urbanization and agriculture; resulting in concerns about increased nutrient levels and an increase in the number of weed species within the riparian zone. Over a number of months students and stakeholders participated in a multidisciplinary design process to create a learning resource 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 *Design Day* was an opportunity for the students to develop their ideas about the design of the educational resource, propose possible formats, identify constraints and generate a consensus upon which a brief for the multimedia designer could be written. Participants included expert learners (the students), who ranged in age from 12 to 17 years, and experts from education, environmental science and multimedia design. The *Design Day* began with each of the expert groups outlined their desires and constraints for the design of the educational resource, and these initial parameters were summarised and referred to during the rest of the day. In the Design Studio (the Design Studio is a multimedia educational design research facility at the University of Sydney: http://sydney.edu.au/research/stl/facilities/EDRS/index.shtml) 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 (https://dschool.stanford.edu). The *empathize* stage took the form of a whole group brainstorming activity during which the initial desires and constraints 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. During the third stage, *ideate*, the participants worked in groups according to discipline area. One group contained all the adults including educators, multimedia designers and environmental scientists. The other three groups each included between five and six students – expert learners. During the *ideate* stage, participants were asked to generate ideas. They were asked not to limit themselves to their knowledge of technology and were instructed to record all ideas. The intention was to explore a wide solution space so that, later in the *Design Day*, these ideas could be distilled into one coherent solution and a brief presented to the multimedia designer for the creation of a resource prototype.

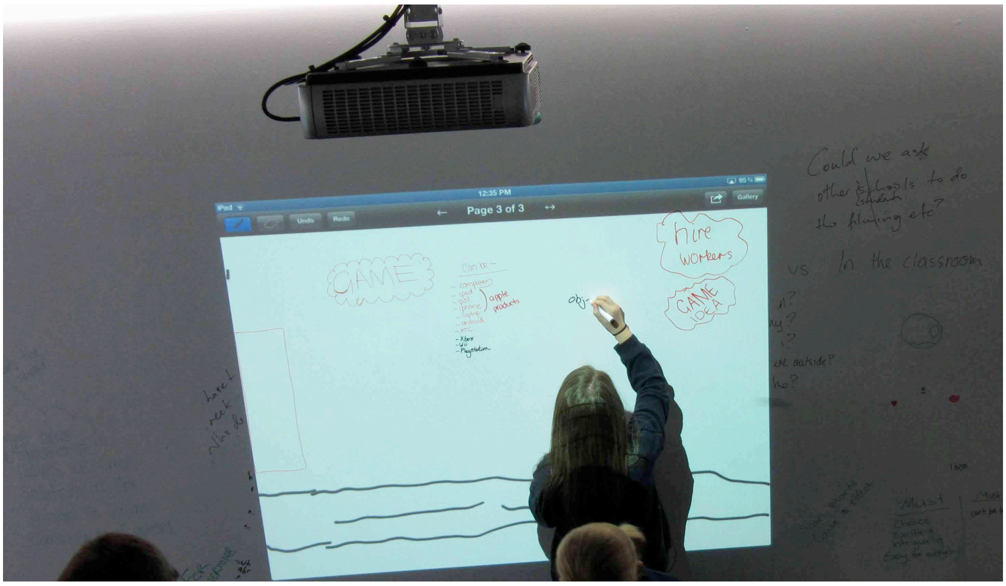


Figure 1: Students working on the design task

This paper follows one of the student groups during the *ideate* stage of the design day. There were five members of the group, three females and two males, whose ages ranged from 12 to 16. Video, audio and photographs of the collaborative design work were collected. Each group was given a choice regarding the digital tool they used (computer, interactive whiteboard, or iPad). This group chose to use an iPad that was projected onto a wall painted in whiteboard paint (a ‘white-wall’, see Figure 1). The transcription of their discourse was analyzed 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. CPACS is a multi-level coding scheme that includes macro-levels (action and content) as well as micro-levels (pronouns, tense, modality, and attitude) of discourse; only the macro-level code, *Content*, was used in this paper (Kennedy-Clark & Thompson, accepted). The Content section of CPACS contains six codes: phatics (social – phatics, salutations, leave taking), planning, topic, task, tool use, and off-task. Initial agreement between raters was 52%, after discussion 96% agreement was achieved. 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 decision-making (Thompson & Kelly, 2012) and content (Kennedy-Clark & Thompson, accepted) in discourse, and will be used in the analysis presented here. Markov transition diagrams illustrate the probability of each state transition (for example, from topic to task), and are appropriate for processes in which there is an expected order of states.

Analysis

The ideas considered to be important to the development of the group’s design were identified in a transcript of the group’s discourse. Selection was based on key descriptors of the final design, rather than methods of implementing the design, or examples of existing games the students used as inspiration. They are presented in Table 1, below.

Table 1: Idea development

Idea	Description	Proposed by
1	Original illustration	Sue (Mark)
2	A computer game	Sue
3	Access to technology	Steve
4	“taking care of”	Philip
5	Managing	Philip
6	The Creek	Philip
7	“challenge others”	Steve/Mark
8	Levels of difficulty	Steve/Anna
9	“a player in the game”	Anna/Steve

10	Gaming platforms	Mark
11	Different game "views"	Beth
12	Role playing	Mark
13	Violence	Philip
14	Score, points and awards	Anna
15	School subject and class	Steve

There were 15 ideas that were directly relevant to the development of the group's design. The number also represents 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*, and *The Creek*) occurred in quick succession; they are closely related and were suggested by the same person (Philip). Violence, however, was less related to other ideas and could almost be considered tangential. It is possible that this was an idea stimulated by a 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 15 have been assumed to be of equal importance to the final design. Table 1 also shows the name of the group member who first put forward an idea. Steve, the facilitator, played an important role during the design process and on more than one occasion he reflected an idea suggested by one student, helping the others to recognize the contributions of all to the design process and the final product.

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 five students and the facilitator), taking the generation of ideas into account. This is presented in Figure 2.

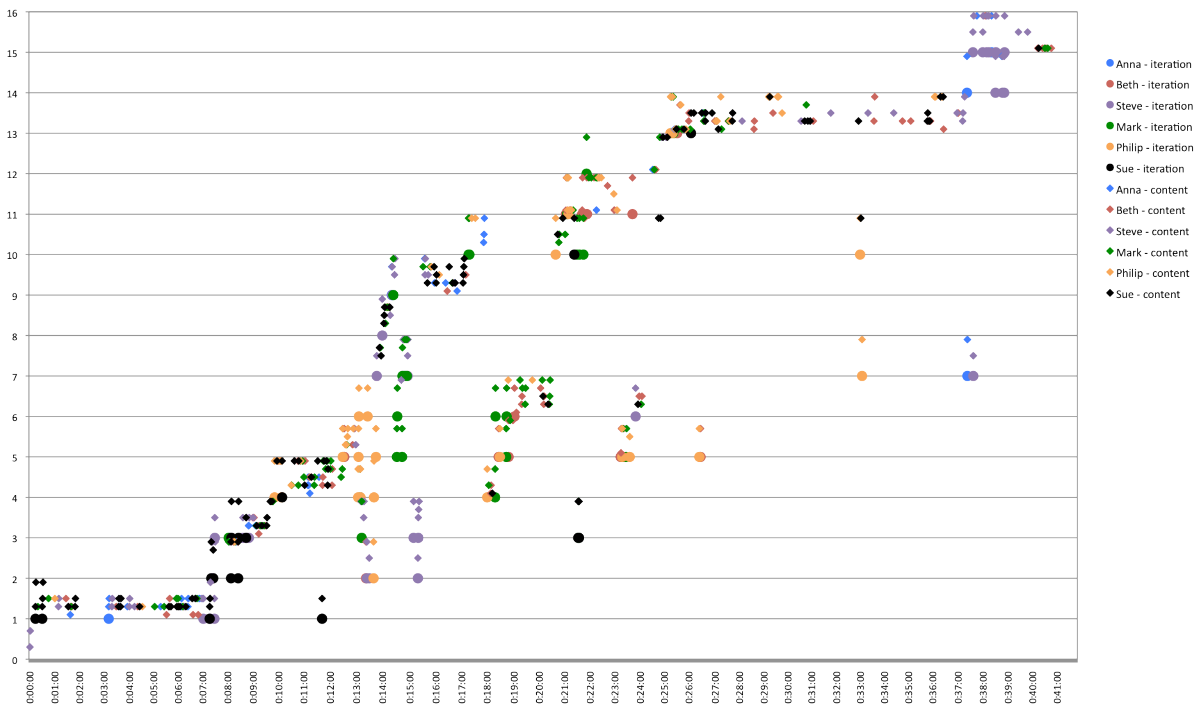


Figure 2: Iterations of the design, and associated conversation

Figure 2 shows the development of ideas during the process of design, for each member of the group, and the *content* of discussion. 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 did this for two reasons: (1) the notion of design assumes a cumulative and revised whole; (2) it was those moments where iterations emerged that we examined more closely. Each participant has been given a different colour. Circles are the utterances that 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 (*content* codes): Sue was active in this discussion (black). 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 analyzed in detail.

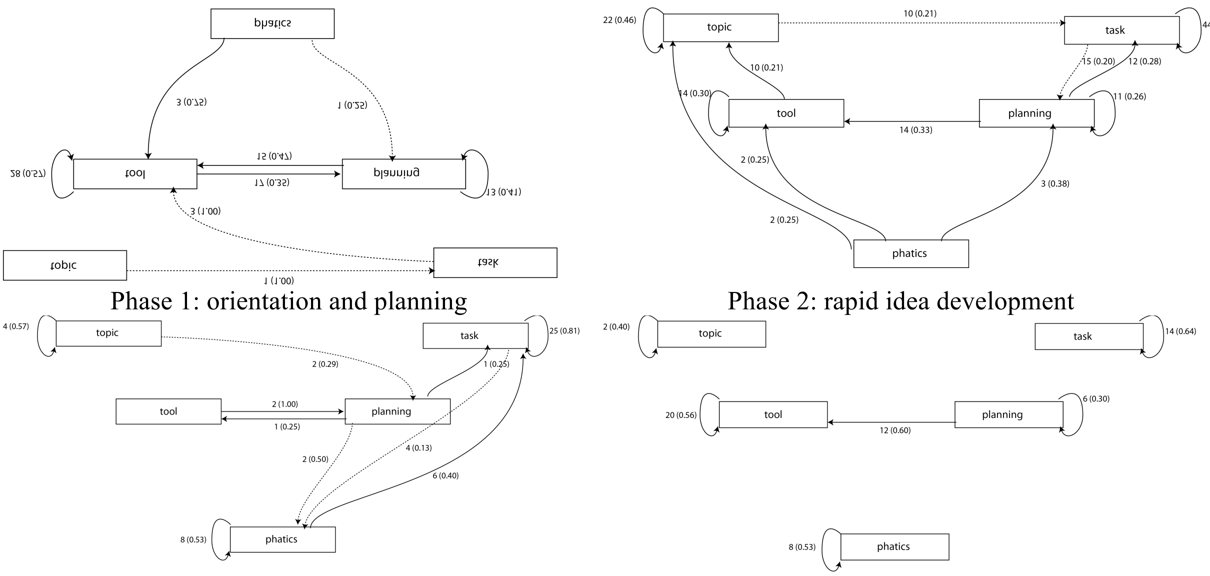
The collaborative design work analyzed here opens with a longer period of discussion, following on from the initial idea. This consists of activity and conversation that seeks to organise and orientate the group in terms of physical space, available tools and the task at hand. It includes discussion 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 her 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 that follows includes familiarizing themselves 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 (the facilitator) returns that Philip justifies their discussions by relating it back to the project. After this, a chain of closely related ideas is put forward that includes *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 observing Beth, Mark and Sue sketching characters on the wall, gains Steve's attention for feedback on their progress. Steve continues using the techniques he employed earlier, 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 still works and the entire wall is available for writing on. At this point, members of the group seem distracted by the other groups also working in The Design Studio, 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 point where the notion of violence is introduced, which results in a heated verbal exchange after which he withdraws altogether 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.



Phase 1: orientation and planning

Phase 2: rapid idea development

Phase 3: Social interactions

Phase 4: Technology failure

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 (see Thompson & Kelly, 2012 for more on interpreting Markov transition diagrams). 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 ten.

In the Phase 1 transition diagram, there is a clear emphasis on planning and the tools that would be used. Socially based utterances (phatics) were followed by those connected to either tool use or planning. If members discussed tool use, they either continued discussing this (0.57) or moved to planning (0.35). 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 and this supports the in-depth analysis. This design work was characterized by productive discussion, with few distractions; the group members appear to be focused on their design work.

The in-depth analysis identified phase 3 as the end of idea development, and a focus on social interactions. The First-Order Markov transition diagram supports this finding. The link from phatics to itself (53%) shows that group members remained discussing this 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, 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 the only link between elements: 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: the links were distributed between so many different elements that none had a high enough probability or frequency to be displayed.

Discussion and Conclusions

The aim of this paper was to describe the processes of design observed in a group of five students during a *learning by design* task. Multimodal analysis has provided insights into relationships between the patterns of the content of discussion, the generation of ideas, and the phases of design work. One measure of the success of this group was the organic nature of its designerly behavior. While we only concentrated 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.

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 the resource under construction (Linn, 1996). Opportunities for reflection were incorporated into the productive phase of idea 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 to 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.

Students' use of tools was a key part of their idea development and record keeping. Further analysis (Thompson, Ashe, Wardak, Yeoman & Parisio, accepted), investigated how the tools available in the dedicated design space effectively supported the collaborative design work of the members of the group. The tools were a central element of discussion and productive design work (Figure 3). They were an aid in collaboration allowing for the articulation of the ideas of individuals on the white-wall and in creating a space in which all ideas were combined in the more permanent record keeping on the iPad. Interestingly, it was the social interactions that seemed to interrupt the regular pattern of idea generation as was seen in the Markov diagrams.

The learning outcomes for students participating in this project relate to 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 (Thompson et al., accepted), throughout the collaborative task. The students agreed that the ecosystem in question needed to be managed in terms of human impact on this system, and that there should be shared use; mostly for urbanization (most familiar to these students) rather than 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. 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.

By extracting multiple streams of data, visualizing and analyzing the processes of learning, phases of idea generation, as well as patterns of discourse, were identified. Future research will apply these to the analysis of the other groups that participated. Comparisons between the groups will then 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 study, the facilitator played a significant role. Given that he visited all groups, his role can be further interrogated. 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.

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* task. We have shown that students were able to articulate an understanding of some (often challenging) ideas about systems. In addition the development of ideas as they related to the final design were identified and visualized. Through these visualizations, phases in the design work were identified 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 LBD 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.

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