# From Behaviour To Design: Implications For Artifact Ecologies As Shared Spaces For Design Activities

Christina Vasiliou[1], Andri Ioannou[2], and Panayiotis Zaphiris[2]

*[1] NorSC Lab, Department of Computer and Information Sciences, Northumbria University, Newcastle upon Tyne, UK*

*[2] Cyprus Interaction Lab, Department of Multimedia and Graphic Arts, Cyprus University of Technology, Limassol, Cyprus*

## Corresponding Author:

Christina Vasiliou
Department of Computer and Information Sciences
Northumbria University
Newcastle upon Tyne
NE1 8ST
United Kingdom

e-mail: christina.vasiliou@northumbria.ac.uk

e-mail: vasil.christina@gmail.com

# From Behaviour To Design: Implications For Artifact Ecologies As Shared Spaces For Design Activities

Researchers are increasingly exploring collaborative behavior in complex socio-technical systems through in-the-wild investigations to understand, evaluate and re-design space and technology. The space configuration and tools available in such activities are crucial for the successful collaboration of a group. This work offers an in-the-wild examination of six groups tackling a design project working in an artifact ecology, a space rich in physical and digital artifacts. We delve into the physical and digital space of each of the groups during a 3-month duration to obtain a rich understanding of their collaborative activities. The aim of this work is two-fold; provide summative narrations of each one of the five models of DiCoT to extract design implications and evaluate the usefulness of DiCoT as an analytical tool for understanding artifact ecologies. Through a rich dataset – interviews, focus groups, reflective diaries, online interactions, and video recordings – we construct a summative description of the group behavior based on the methodological framework of Distributed Cognition for Teamwork. Drawing on these narrations, we provide design implications on the use of an artifact ecology as a shared space for design activities. Both outcomes are then used to evaluate the usefulness of DiCoT as an analytical tool for artifact implications.

Keywords: distributed cognition; artifact ecology; CSCW; shared spaces;

## 1. Introduction

Ellis, Gibbs and Rein (1991) defined the concept of shared spaces as an environment where individuals and tools interact and collaborate. More specifically, the term 'spaces' represents the concept of physical space as understood in the real world (Benford, Brown, Reynard, & Greenhalgh, 1996). Proposing a spatial-oriented approach, Bendord et al. (1996) expanded the concept of shared spaces to the blend of both “physical and synthetic” worlds. Since then, the evolution of technology led researchers to construct a diversity of spaces for collaboration including digitally augmented physical spaces (Martinez-Maldonado, Clayphan, Ackad, & Kay, 2014) (Price & Rogers, 2004), or virtually-driven collaboration spaces (Dullemond, van Gameren, & van Solingen, 2014). In this work, we approach the concept of shared spaces from the perspective of Bødker and Klokmose (2012) that defined such an environment as an artifact ecology, a space rich in technologies – physical or digital – that co-exist and collaborate. However, designing and appropriating a technological set-up such as an artifact ecology to support collaboration between individuals can bring up new challenges. Bringing together people with different background and expertise raises concerns over the design of the tools and interactions in the artifact ecology.

As highlighted in industrial approaches such as contextual design the challenge for a technology designer is to construct a detailed understanding of the user behaviour and the possibilities introduced by a prospective technology (Beyer & Holtzblatt, 1999). We can obtain this rich understanding by studying a user in its natural settings to propose design implications for the technology in need. Furthermore, recent work in HCI highlighted the need to prototype and understand complex technological set-ups in-the-wild (Crabtree, Chamberlain, Grinter, Jones, Rodden, & Rogers, 2013). Such approaches were constructed on the basis of cognitive science and the concepts of ecological and distributed cognition (Hutchins, 1995). This work aims to build-up on previous ethnographic research conducted to identify how interactions and work are distributed in a co-located group working within a multi-device setting, with a particular focus on design activities with both physical and digital objects. More specifically, our objective was to provide summative narrations of each one of the five models of DiCoT and extract design implications for constructing artifact ecologies. Furthermore, this work also aims to evaluate the usefulness of DiCoT as an analytical tool for understanding artifact ecologies.

We structure the current work in two stages. First, demonstrating how to construct summative narrations for group behaviour mapping the collaborative design activities of six groups based on the methodological framework of Distributed Cognition for Teamwork (DiCoT) (Blandford & Furniss, 2005). Then, drawing on these behaviour narrations, we provide design implications on the use of an artifact ecology as a shared space for design activities , taking into account the fine line that connects and divides the physical and digital space. Thus, the work contributes to the HCI community by demonstrating an across-the-board view of collaborative behaviour during design activities in an artifact ecology. Drawing on both theoretical and industrial perspectives of DiCoT, it complements the existing research on the design of artifact ecologies.

The paper begins by reviewing the contributions of distributed cognition, contextual design, and DiCoT as methodological approaches that guide the design of artifact ecologies and collaboration technologies by understanding group behaviour. Following the structure and theoretical background of DiCoT, we analyse groups' collaborative behaviour and summarize them through the five narrative models of DiCoT. The rich understanding constructed through the analysis allowed us to consider design aspects of artifact ecologies as shared space for design activities. We present our findings in the form of design implications that may inform the design of artifact ecologies for collaborative design activities.

## 2. Related Work

In the following section we review how distributed cognition, contextual design and DiCoT framework contributed to the understanding of human behaviour to design shared spaces and artifact ecologies.

### *2.1.Artifact Ecologies*

As Bødker and Klokmose (2011) highlighted, objects become artifacts because “they are designed or shaped by human beings with a particular purpose or use in mind”. This has been the focus of the HCI community; creating computing artifacts that will be useful, and users will understand their purpose. Beguin and Rabardel (2000) introduced the relationship between the artifact and its user, proposing that artifacts also become instruments based on the context of the user’s activity. As an artifact becomes transparent and seamless during an interaction, the user considers it as part of its body. Therefore, to aid in the design of interactive artifacts, we need to reflect on the level of transparency it may provide in a cultural context.

In this work, we approach the concept of shared spaces from the perspective of Bødker and Klokmose (2012) that defined such an environment as an artifact ecology, a space rich in technologies – physical or digital – that co-exist and collaborate. These technologies communicate and share information with each other, creating an independent network for communications (Jung et al., 2008; Bødker & Klokmose, 2011). Further, Loke and Ling (2004) explained how these devices interact “with one another, with users, and with Internet” (p. 78). Researchers have used the metaphor of “ecology” to indicate the cohabitation of multiple heterogeneous devices that are interlinked, acting as one unified system. However, in this work, we further claim that an artifact ecology can incorporate various artifacts that support the same objective using different approaches or attributes. The quantity of technologies provided it is directly associated to the number of individuals using the artifact ecology. That is; when the number of individuals increases, the number should increase but still encouraging collaboration (not a one-to-one analogy).

### *2.2.Artifact Ecologies in Collaborative Settings*

Working in different fields ranging from applications in education (Poole et al., 2011), workspace (Chin et al, 2011), healthcare (Furniss & Blandford, 2010) and domestic settings (Lee & Šabanović, 2013), researchers focused on understanding human-artifact interactions to propose or revise technological solutions.

Researchers in CSCW explored how to put together different tools to support and coordinate a team. For example, MultiSpace (Everitt, Shen, Ryall, & Forlines, 2006) included a tabletop as a central focus, an interactive wall, and personal smartphones and tablets for mobility during a staff meeting. Even though the tabletop space enhanced the democratic interactions, the team would use artifacts in the ecology based on the given tasks or their personal preferences. GreenTouch, on the other hand, combined the tabletop surface with mobile devices and a web-application for sharing data in the "cloud" (Valdes et al., 2012). Both studies highlighted the complexity of interactions in such a multi-artifact space and emphasized the difficulty in predicting the interactions that users would perform with each device.

Focusing on facilitating problem-solving and increasing engagement during collaborative activities researchers designed and augmented classrooms and informal learning contexts with technologies, blending different devices and tools into artifact ecologies. These artifact ecologies have been used in various education domains such as engineering, design, language learning, while researchers examined their benefits from different perspectives. For example, artifact ecologies have been designed to improve problem solving activities (Hilliges et al., 2007), support classroom learning (Rick, 2009), group coordination (Coughlan et al., 2012), boost creativity in design conversations (Bardill, Griffiths, Jones, & Fields, 2010), or support co-present design work (Martinez-Maldonado et al., 2017).

### *2.3.Understanding and Evaluating Artifact Ecologies*

To understand the complexities of such settings, researchers used either in-the-wild investigations or ethnographic approaches to reveal design implications or within controlled lab experiments to approve or dismiss hypothesis about the design of an artifact within an ecology. For example, Pantidi et al. (2009) focused on how different surfaces and input methods aid collaboration during brainstorming and writing sessions. Researchers have also attempted to explore and test the design features and performance of different artifacts within an artifact ecology using controlled lab environments. For example, Houben, Tell, and Bardram (2014) introduced and evaluated ActivitySpace, a configuration space that allows the user to combine and work across devices. The evaluation took place in a controlled lab, testing a scenario with six key features of ActivitySpace. The scenarios and controlled environment allowed researchers to focus and test specific design elements of the artifacts and ecologies. However, relying on potentials and problems based on previous experiences and similarities from other artifact ecologies can be problematic, revealing the need to identify context-specific design considerations. Thus, researchers stressed the importance for both in-situ design and evaluation approaches for multi-device and multi-participant spaces (Houben et al., 2015; Houben et al., 2016).

### *2.4.Distributed Cognition*

Distributed cognition (DCog) is a theory that originates from cognitive science and understands cognition in a distributed manner; across objects, individuals, artifacts, and tools in the environment (Hollan, Hutchins, & Kirsch, 2000) (Hutchins, 1995). DCog emphasizes the ways that the environment assists cognition through physical and technological means, with a particular focus on the coordination between individuals, artifacts and the environment (Rogers, 2012). It underpins two key arguments:

ecological expansion of cognition and embodiment of information in system representations (Hollan, Hutchins, & Kirsch, 2000). Firstly, the ecological development of cognition rethinks the boundaries of cognition expanding them towards elements that may participate in a cognitive process. Secondly, the embodiment of information in system representations is closely connected with the mechanisms that individuals perform using not only internal information but also knowledge and processes associated with external objects.

As an analytical tool, DCog allows researchers to grasp the human cognitive capacity considering the context of activities and propose or updated existing processes and design features. For instance, Deitrick et al. (2015) draw on DCog theory to demonstrate a descriptive representation of collaborative learning and interaction patterns within k-12 students during computer music programming. The researchers structured their findings around two major themes: choosing what to program and representing transformation. Following an entirely different approach, Mangalaraj et al. (2014) examined different design patterns for distributed cognition in a controlled experiment among software practitioners. The aim was to investigate the effects of distributed cognition with regard to pairing in software design teams. Furthermore, through the findings of a DCog analysis, researchers can identify what is prominent in the current design of a system or environment to create effective human-computer interactions.

The various research studies indicated that a DCog analysis can be performed on different levels; from the conceptual level of developing products with the ideas of DCog in mind to examining in-depth the existing practices to discover breakdowns and design requirements. However, what was also evident was the lack of clear structure in a DCog analysis, which can help a design team through the data collection and interpretation phase.

### *2.5.Contextual Design*

The term Contextual Design (CD) originates from Beyer and Holtzblatt's (1997) work and captures an industry based user-centred design process that encapsulates an in-depth understanding of how users currently work. CD encourages the product designers to get involved in data collection and guides the interpretation of collected data for the best product design results (Beyer & Holtzblatt, 1999). The first step is a contextual inquiry, used to understand the users' real-world behaviour and reveal details and motivations about day-to-day activities. It involves field observation and interviews in their workspace to allow the design team to develop a shared interpretation of users' work. This information is later on used to model and organize users' behaviour in five models – workflow, sequence, culture, artifact, and physical (Beyer & Holtzblatt, 1997). Through the development of these five models, the design team develops a shared view of the user's needs and considers design issues to handle the problems in the existing processes. The structure that CD encompasses provides the necessary robustness for the design team to base design decisions on evidence and verified claims.

The clear structure and robustness in interpreting data encouraged researchers on using it throughout the years in field-based investigations, from the workplace to healthcare settings. For example, using CD Löffler et al. (2015) focused on social and environmental aspects of a desk-based office to improve workplace sedentary behaviour. Focusing on collaboration patterns amongst emergency room managers, Randall et al. (2013) followed a more generic CD methodology to identify a set of technological requirements and design features.

### *2.6.DiCoT Methodological Framework*

Drawing on ideas of DCog and the robust structure of CD, Blandford and Furniss (2005) developed DiCoT; a methodological framework that structures the data interpretation around DCog theory. Building on the five models included in a CD analysis, DiCoT re-orients and enriches them with principles based on DCog theory: (i) information flow model, (ii) physical model, (iii) artifact model, (iv) social model and (v) evolutionary model (Blandford & Furniss, 2005) (Sharp, Robinson, Segal, & Furniss, 2006). The following table (see Table 1) summarizes the five models included in the DICoT methodological framework.

| **Model** | **Description** |
|---|---|
| **Information Flow** | Focuses on the way information circulate and transform throughout the cognitive system; considering data movement, buffering, and transformation. |
| **Physical Layout** | Focuses on the physical structure and ergonomics of the socio-technical system; considering the location of tools and individuals in the environment. |
| **Artifact** | Focuses on the design, features and limitations of important artifacts in the cognitive system, such as representing and scaffolding activities. |
| **Social** | Focuses on the social roles, relationships, and goals and the way the environment is socially distributed. |
| **Evolutionary** | Focuses on the evolution and differentiation of the system over time, considering cultural influences and development of expertise. |

Table 1. The models underlying DiCoT (Blandford & Furniss, 2005) (Furniss & Blandford, 2010)

Analysis using the DiCoT framework involves capturing a rich data set in the field of the users and constructing detailed reports of the different models of DiCoT framework. Such a descriptive analysis can help researchers understand the existing design of a system and reveal design insights for tools, processes, and the context (Furniss, Masci, Curzon, Mayer, & Blandford, 2015). For instance, Furniss et al. (2015) applied the DiCoT framework to explore and improve the design of a medical device in different layers of the socio-technical system. The authors constructed rich descriptions of all five DiCoT models centralized around the medical device under investigation. As they further explained, the analysis allowed them to identify design implications that reflect both the design of the device as well as the broader system.

Targeting to improve a system on a particular layer of activities, Sharp et al. (Sharp, Giuffrida, & Melnik, 2012) focused on the flow of information to map the interactions and coordination behaviour of a dispersed team. By immersing themselves in the activities of an agile team that is distributed in multiple locations, they provide a rich narration of the physical layout, artifact and information flow models focusing on the mechanisms the team uses for successful collaboration. Through the in-depth involvement and analysis of the team, the researchers identified distinctive characteristics that differentiate dispersed from collocated teams and what challenges should be considered in the design of shared spaces.

Overall, up to date research has proven that DiCoT can be used to understand the complex interactions and interconnections in sociotechnical systems. Both in-the-wild investigations and structural approaches to interpreting data can provide design insights and implications regarding both technological and social aspects of the system. Thus, it can be ideal in the current context where we aim to explain collaborative design activities within an artifact ecology in five different layers and extract design implications.

## 3. Setting

### *3.1.Participants*

Participants (N=31) in this study were six groups comprised of four to six postgraduate students enrolled in a Human-Computer Interaction optional course (Age span = 22-45 years old, M=29.1). The instructors assigned students into groups based on their background but without assigning specific roles, forming multidisciplinary groups to resemble real-world design teams. Participants come from a variety of backgrounds that can represent a valid sample of a possible work population. For instance, each one of the groups included at least one member that had a first degree in computer science with practical experience in developing and designing software and mobile applications. Similarly, we made sure that all groups have a member with expertise in graphic design that will feed the group with creativity as well as support the visualization tasks for the product design. The rest of the group members had background and expertise in communication and internet technologies, language acquisition, learning analytics and cognitive psychology, supporting the multifaceted needs of this project.

### *3.2.Context*

The present study ran in two classes throughout 2013-2014 to capture a broad perspective of how an artifact ecology may be used by different groups and individuals. The two classes provided a comprehensive insight of various mechanisms of distributing cognition across the physical and digital space of an artifact ecology. The class is related to human-computer interaction, providing a practical and real-world exemplar of user-centered design (UCD) process for the design of a product. The classes met face-to-face once weekly for 3 hours for 13 weeks. In-class activities involved an interactive lecture to provide UCD methods and exemplars and a two-hour practical session in applying the UCD process on a given group project. Between the weekly sessions, the group kept collaborating on the group project as it was a primary deliverable of the course. The hands-on approach aimed to prepare the students for the post-university, professional working context (Zdrahal, Mulholland, Domingue & Hatala, 2000).

### *3.3.User-centered design activities*

User-centered design is a term used to describe the idea of involving end-uses in the design and development of a product or service (Vredenburg, Mao, Smith, & Carey, 2002). It can be applied on many levels; from a lower level of using user-based feedback to revise a product, to a higher level of involving the users as equal partners throughout the whole design process. UCD also represents a general philosophy for good design, providing a collection of methods and practices to collect information and explain user behavior to guide the design process (Karat, 1997).

As design activities, a UCD process involves five phases: analysis, design, evaluation, implementation and deployment. The classes in this study, paid particular focus on the first three phases, leaving out the actual implementation of the designed product. The first phase – analysis – involves the understanding of target audience and capture the requirements for the product. This includes the understanding of objectives, challenges and constrains of users, developing personas, analyzing the hierarchy of tasks and creating scenarios of use. The second phase of design captures the conceptual and functional essence of the product. The groups developed design concepts, conceptual models, storyboards, and high and low-fidelity prototypes of the product. The third phase and final step in the current group work setting is the evaluation of the product through the combination of different methods to revise the product before implementation. Few methods more often used are heuristics, usability testing for low or high fidelity prototypes, cognitive walkthroughs and expert evaluations. During the collaborative sessions the tutors of the course only observed the group activities and were there to provide triggers rather than answer questions or solve project problems, following the problem based learning approach.

### *3.4.Artifact ecology*

Groups' collaborative activities in both classes took place within an artifact ecology; that is a space where technologies co-exist and share information with each other. As highlighted by McNeil and Borg (2017), the design of a learning space can impact the teaching and learning activities in a given setting. Beside the context, factors such as group size, space size and configuration, may also impact the way information is distributed (Li & Robertson, 2011). Thus, for the design of the artifact ecology we took into consideration the aims of the shared space: support research, creative design, reporting, and reflection, for both in and out of class activities. More particularly, the artifact ecology employed three primary characteristics:

- a tabletop projection, physically gathering the group around a central focus point. We used a square table with a rectangular table surface with a projection on top that was connected to a Mac mini and managed through a wireless keyboard and mouse (Bardill, Griffiths, Fields, & Jones, 2010) (Morris, Lombardo & Wigdor, 2010).
- a Facebook private group for each group to view and share group material and information about the group project (Parmaxi & Zaphiris, 2015).

- a collection of mobile devices with different sizes, such as iPods, smartphones, and tablets, to support concurrent activities (Vasiliou, Ioannou, & Zaphiris, 2014).

The instructors set up four identical settings to allow four individual groups working at the same time. Furthermore, they advised groups to appropriate the provided technologies for each activity and task, as well as include and consider personal devices as part of the artifact ecology. Group members were also allowed to post material freely and manage the Facebook Group as owners of the group.

# 4. Methodology

This work aims to build-up on previous ethnographic research on how interactions and work are distributed in a co-located group working within a multi-device setting, with a particular focus on design activities with both physical and digital objects.

## *4.1.Research Questions*

The main objectives of this study is to provide summative narrations of each one of the five models of DiCoT and extract design implications for constructing artifact ecologies. Furthermore, this work explores the use of an artifact ecology in-the-wild by six groups tackling a design project using DiCoT to evaluate how it can as an analytical toolkit and assist us with the design of artifact ecologies. Thus we identified the following two research questions to be the central pillars of this study:

- What design implications emerge for constructing classroom artifact ecologies for design activities?
- How can DiCoT assist us with the design and evaluation of artifact ecologies for design activities?

### 4.2. Data Collection

We collected data using a variety of approaches: field notes from in-class observations throughout the course and learners' reflective diaries. We further conducted focus groups and individual semi-structured interviews towards the end of the course to extract qualitative information regarding the strategies and procedures group members developed within the artifact ecologies. Furthermore, we enriched our results through video recordings of the collocated collaborative activities within the artifact ecology. We also captured and reviewed the timeline of activities of each group through Facebook data to triangulate our findings (N=6), through the NCapture add-on by NVivo. Table 2 summarizes the types of data gathered from the six groups. This data source allowed the researcher to gain insight into the online interactions of the group between the meetings, verify the data from self-reported sources and gather in digital form important artifacts of the collaborative activities (e.g. prototype sketches).

### 4.3. Data analysis

We based our analysis on the DiCoT methodological framework developed by Blandford and Furniss (2005), using DiCoT principles as the coding scheme as clearly outlined in the work of Sharp, Robinson, Segal, and Furniss (2006). Each DiCoT principle represents a code, resulting into 22 codes classified in five DiCoT models portrayed as categories. Considering these models and principles as the foundation of our analysis, allowed us to examine how different groups working collaboratively within an artifact ecology exhibit the various perspectives of DiCoT.

We initially reviewed the entire data corpus to gain a general sense of our data. The data corpus from the two classes under investigation, included tutors' field notes, students' reflective diaries, focus groups and semi-structured interviews transcriptions (as seen in Table 2). Further, we also examined the interactions that occurred within the

Facebook group of each group and the physical interactions taking place within the artifact ecology through the video recordings, identifying sections with mechanisms related to distributing information. This initial review served as a comprehensive account of the overall behavior of groups, during the course and video segments or Facebook sections for further coding.

We then imported the dataset in NVivo for detailed qualitative analysis. We coded the data to the associated DiCoT principles. For example, a video segment representing a group member standing up to view the whole projection was coded under "horizon of observation" (Principle of the Physical Layout Model). In another instance, a Facebook upload of an initial prototype sketch was coded under "information transformation" (Principle of the Information Flow Model). To increase the reliability of our coding, one researcher initially coded only a small part of the data (one focus group, two interviews and one video). A second researcher reviewed the coding and met with the first researcher to agree upon the codebook.

| Data | Purpose | Data Analysis | Class1 | Class2 |
|---|---|---|---|---|
| Students' Reflections | Self-reporting on their group activities and strategies | Thematic analysis | + | + |
| Instructors' Field Notes | Overview of the group-work plan and activities held during each session | Thematic analysis | + | + |
| Facebook Group Timeline | Insight into group online interactions and verify elf-reported data | Quantitative analysis for triangulation | + | + |
| Focus Group | Reflection on the process, activities and tools provided | Thematic analysis | + | |
| Videos | Physical interactions and information flow examples. | Coding in thematic video segments | + | + |
| Semi-structured Interviews | Capturing activities, procedures, and outcomes. | Thematic analysis | | + |

Table 2. Overview of data collected from the six (6) groups.

Through this analysis, we could identify how each principle was enabled or not by each group and compare and contrast the mechanisms used, constructing a summative description for each model. The descriptive accounts allowed us to identify and determine design principles of artifact ecologies as a shared space for product design activities.

## 5. Findings

In the following sections we describe the use of different types of digital and physical tools as part of an artifact ecology for collaborative activities. We follow the structure of DiCoT methodological framework; classifying information under the five models: (a) Information Flow, (b) Physical Layout, (c) Artefacts, (d) Social Structures and (e) Evolution over time.

### *5.1.Dicot model descriptions*

#### *5.1.1. Information Flow Model*

During the collaborative activities, the information propagated around the system in different ways, such as verbal communications, gestures on the projector, moving physical or digital artifacts. From the videos we observed that group members communicated face-to-face, commenting on lecture notes and brainstorming ideas on the projection. Group members passed digital artifacts such as tablets and smartphones in addition to physical artifacts. This mechanism triggered more discussion around the interactive artifact at hand.

In addition to the way information propagated between individuals, the Facebook group allowed the information movement between different artifacts in the ecology. For example, as indicated by one of the participants:

P25 Interview (Class 2, Group 1): The common ground between everything was the Facebook group. Meaning that the information that an individual was viewing on the laptop or tablet, he would send it directly to Facebook for the rest to review.

As the group further explained during the focus group, at times they were using more than one tools for research purposes, including projectors, laptops, and tablets. Similarly, the groups shared their findings, sketches or project deliverables (see Figure 1) with the rest of the group on Facebook, performing the role of a sharing platform and buffer, so that information is immediately available for all users as well as devices.

One mechanism used repeatedly by all six groups, was the digitization of materials. Sketches and notes developed during class were captured using smartphones and shared on the platform as seen in Figure 2. Recording their in-class discussions was also important for the groups. As expressed by one of the groups:

P2 Reflections (Class 1, Group 1): We also decided to record our in-class conversations for reference, because it is proving very difficult to write everything down, especially when everyone speaks eagerly and spontaneously.

The same group also used screen recording materials to capture video chats that occurred between face to face sessions. As highlighted by P2 during the focus group, even though they rarely went back to listen to their sessions, the video material was easier to scan through and recall what was discussed.

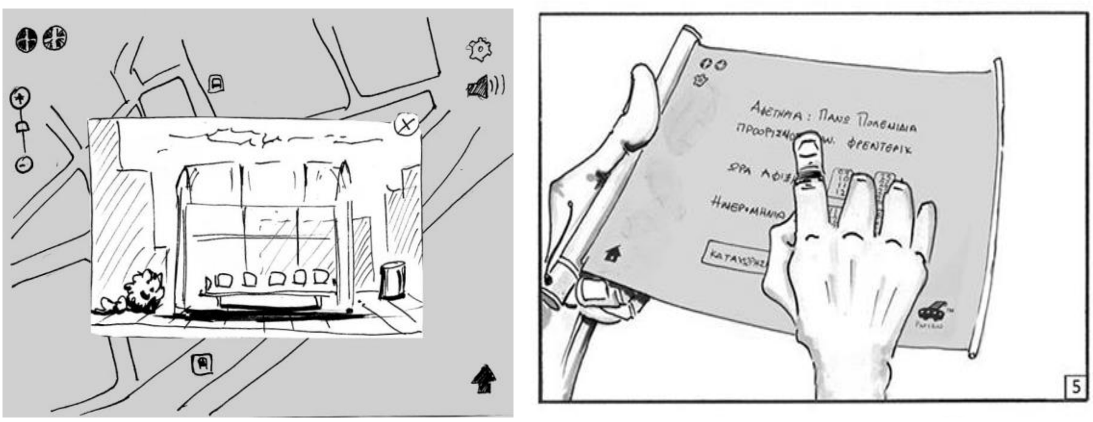


Figure 1. Low-fidelity prototype and storyboard frame shared and discussed on Facebook from Class 2 – Group 2.

Figure 2. Table seating arrangement for Class 1 – Group

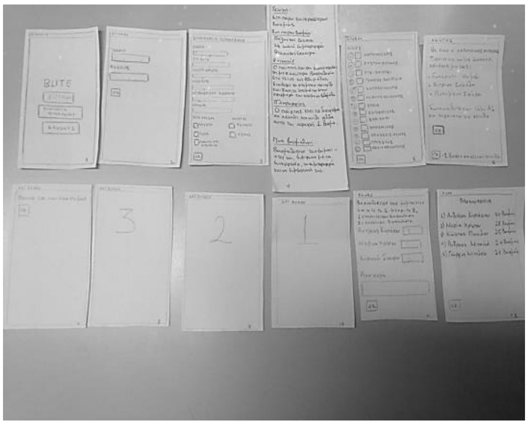
Another pattern in the flow of information around the ecology was the transformation of information from textual to verbal. For example, reading notes out loud to distribute information and insight over group activities towards the group. Even though individuals neglected the particular mechanism during focus groups or interviews; it was evident repeatedly from the video recorded sessions. For example, when looking for certain information from the lecture notes, one participant would read out loud for the rest of the group to listen and reflect upon the information (Class 2, Group 2). In another instance, the participant would read out loud what she was writing down, for the group to verify and comment on it as she was writing, receiving instant approval by the rest of the group (Class 1, Group 2).

### *5.1.2. Physical Layout Model*

The appropriate use of space can simplify perception and cognitive processing, dividing each task into functional units (Hollan, Hutchins, & Kirsh, 2000). One of the ways the group used the space to support cognitive functions is the position of the projection in conjunction with the printed notes and documents. These items were used as steady representations within the artifact ecology; including the general project goal, objectives for the particular session, or project activities through Facebook group timeline. On top of the projection, the groups often used a printed document of the lecture to examine triggering points provided by the tutor. As explained:

> P2 Focus Group (Class 1, Group 4): At the beginning of each session we would get the lecture notes and discuss what we have not completed from previous meetings. Then we would assign tasks to complete the forthcoming week.

Another instance where the spatial arrangement of artifact supported cognition was during the review of the prototypes. As seen in the video of the Group 1 from Class 2, members laid the printed prototypes on the table and put them in the correct order to review them as a whole. Setting prototype frames next to each other, provided a holistic view of the prototype from start to finish to compare current and goal state in the same physical space (see Figure 3). The table and the seating arrangement benefitted the group's collaboration and communication.



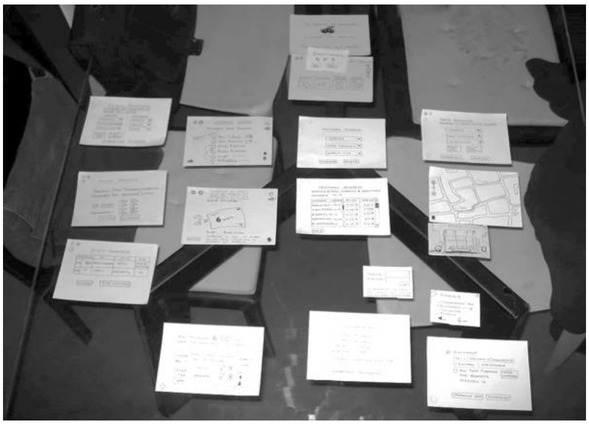


Figure 3. Low-fidelity prototypes laid on the workspace of groups. Left: Class 2, Group 1, Right: Class 1, Group 2.

Groups indicated that working on the projector was more "convenient". During the first sessions, their work on the projection was seamlessly blended with their paper notes, permitting them to go back and forth easily. As one of the interviewees stated:

> P23 Interview (Class 2, Group 2): You could have the keyboard on your knees, type down whatever and if you wanted something, for example, you could see it on the spot, even on top of the paper.

During their discussions, group members enabled spontaneous bodily movements such as pointing on artifacts projected or physically laid on their shared workspace. The projector handler was directed by the rest of the group to switch between browsing, documenting work, or overviewing progress through Facebook. These interruptions can be classified into three types: suggestions, instructions, and clarifications. To aid such interruptions, the group used hand movements as an exhaustive way to express directions.

In addition, groups indicated that visually representing starting point and end point of the group work help their motivation. As group members explain during the focus group:

> P20-P21 Focus Group (Class 1, Group 4): We think that the reason we felt so concentrated on our tasks was because we had defined from the beginning [of the session] a very specific and clear target, starring at us the whole time.

#### *5.1.3. Artifacts Model*

Between face-to-face sessions, the Facebook group was extensively used and was extremely valued for coordinating their activities and materials. The groups uploaded their work, ideas and sources on the group and Facebook automatically created a project timeline for all their activities. Everyone had access to it and could upload, share and retrieve information at any time. As one of the group members explained:

> P20 Reflections (Class 1, Group 4): Each one reviews on its own time and uploads on Facebook their notes and thoughts.

Facebook performed the role of the web platform that allowed the distribution of information across the devices while the projector played the role of the distributor among the team members in the class. Furthermore, to direct notifications to team members for particular tasks during the week the groups used tags, directing the notification to the associated member. This technique enabled further discussion towards the particular member to direct the discussion as an expert on the subject matter or provide more information regarding the progress of the task.

In addition to the Facebook group, tablets and tabletop projection were major assistants during collaborative activities in face to face sessions. Tablets were considered significant within the workspace since they provided a means to capture and transform information in other forms. As one group indicated during focus group, they used smartphones to capture with photos something that they had sketched or written and then posted on the group.

> P28, Focus Group (Class 2, Group2): Before we leave from here [class], whatever we had created was uploaded directly to Facebook.
> P30, Focus Group (Class 2, Group 2): Most of the times, with a sketch or writing something on paper, we would take a snapshot of it and then post it on the Facebook group.

However, they were considered "too small" (Focus Group, Class 1, Group 1) to facilitate brainstorming, extensive research and note-taking activities. On the other hand, the tabletop projection was used to gather material and groups attention around the primary task of the collaborative work. As one of the group members explained in his reflections:

> P20 Reflections (Class 1, Group 4): The factor that affected for this great flow is the way the physical workspace was set; that is that we have on our hand exactly

> what we need without moving around to get something and without ruining the flow of our thoughts.

### *5.1.4. Social Structures Model*

The group would divide goals and sub-goals based on each other's capabilities as well as access to information or participants. The group members spread the responsibility of the tasks and decisions equally. Each group member was aware of their individual tasks and responsibilities. The teams structured the sub-tasks and responsibilities to allow overlapping in duties and maintain the robustness of the solution. As groups explained during the focus group:

> P27 Focus Group (Class 2, Group 1): Independently of how many individuals were working on a part [of the project], at the end we would all review it, all discuss it, and express our opinion and then it would be considered completed.

The extent of how social roles emerge and impact the social structure varied from group to group and based on the workspace. As seen in this context, social structure was not imposed but, was rather developed based on the situation and group dynamics. For example, in two groups a clear leader emerged that evaluated and supervised every step of the way. As reflected in the diary of a participant:

> P6 Reflections (Class 1, Group 1): I feel we are still working well together, but at times I feel that the whole group is marching to the tempo pre-set by one particular person, who also tends to apply a lot of pressure to meet certain goals.

In addition to a leader role, another group assigned from the beginning the role of the coordinator as it was considered important for the efficiency of the collaborative activities:

> P8 Reflections (Class 1, Group 2): We decided that someone would play the role of the coordinator by turns, so that we push the team forward.

Another important social aspect of the collaborative activities around the artifact ecology was the issues of privacy raised. One of the groups (Class 1, Group 2) reported that the Facebook group chat was used to avoid posting informal ideas and thoughts where tutors were able to observe and incorporate in their evaluation. Furthermore, the same group kept smaller circles of private communications that disrupted the continuity of the group.

#### *5.1.5. Evolutionary Model*

The team relied on the structure of the course and the different goals that were defined by the lecture each time. As the interviewee expressed:

> P31 Interview (Class 2, Group 2): Depending on the content of the lecture that we participated on that day, we would continue by setting certain objectives to complete.

Furthermore, groups' behaviour and use of the artifact ecology evolved over time depending on members' roles and activities at hand. For example, during brainstorming activities, the groups used the tabletop projection to allow the group's collective cognition around the task.

The Facebook group kept a record of group's discussions around artifacts central to their progress and enabled them to revisit them when necessary. The Facebook group maintained a record of the debates, decisions made during the progress of their work, and members' duties and tasks, keeping an account of the different steps in the user-centred design process. The record-keeping process was necessary to provide group members with the opportunity to revisit their discussions regarding artifacts they created, and review their decisions. Sharing and discussing on their Facebook page, allowed the valuable information exchange to be recorded and for the members to review the timeline of their activities visually.

One of the problems reported by few group members was that the timeline would get re-arranged based on the recent activity of posts. For example, if a member posts a new comment on an older post the post would appear on the top of all posts. However, when reviewing and reflecting on their timeline later on the re-arrangement of the post required them to pay more attention to the dates that the initial posts were made.

### *5.2.Triangulating Findings*

Concerning the content on Facebook as a central artifact for groups' discussion, we coded each post based on an established 5-category coding scheme (Ioannou, Vasiliou, & Zaphiris, 2016). After the coding, we calculated the groups' average frequency of posting within each coding category, as seen in Table 3, illustrating the intensive use of Facebook from all groups. In addition, we performed a chi-square test (analysis of variance between groups) that revealed that there were no significant differences across groups in their use of Facebook. Moreover, Table 3 provided additional evidence (on top of self-reports) of students' engagement in collaborative design activities such as researching of learning issues, reporting, and reflecting. For example, as reported earlier, Facebook acted as a record keeping and communication tool where students posted captured moments or artifacts from the f-2-f sessions for later reflection during the week. Indeed, Table 3 documents this pattern of posting captures or recordings; yet, we can only rely on learners' self-reports to assume reflection on action was linked to this activity (Ioannou, Vasiliou, & Zaphiris, 2016). This step though was necessary to minimize cultural and personal bias that can influence the interpretations of qualitative data.

| Categories/ Codes | Category Description | M frequency | M% |
|---|---|---|---|
| **Captures/ Recordings** | Multimedia elements such as images, audio files, short videos capturing moments of the PBL tutorial (uploads during the PBL tutorial) | 23 | 6 |
| **Reports** | Information acquired from individual members during self-directed study, including word documents, multimedia elements such as YouTube links and web pages (uploads in between f2f meetings) | 162 | 38 |
| **Questions and Answers** | Discussion of emergent issue (in between f2f meetings) | 95 | 23 |
| **Comments** | Likes, comments on captures/recordings, comments on posted reports, general reflections (in between f2f meetings) | 127 | 30 |
| **Social/off-task** | Postings not relevant to the task (in between f2f meetings) | 16 | 4 |
| **Total** | | 423 | 100 |

Table 3. Use of Facebook—Groups' Average Frequency of Codes (N=31; N groups=6).

### *5.3.Design Implications*

Based on these descriptive narrations of the DiCoT models, there are design implications that emerge for both the design of the artifact ecology as well as the broader system of the course structure and instructions. The design implications are outlined in Table 4 in association with the models that they originated from. In the following section we describe the design implications that the DiCoT analysis unpacked, some novel and some known, verifying their applicability in artifact ecologies for design activities.

| Model | Associated Design Implications |
|---|---|
| **Information Flow** | Provide information transformation means<br>Link the physical to the digital space<br>Physicalization of digital material |
| **Physical Layout** | Increase proximity of interaction through contextual awareness<br>Link the physical to the digital space |
| **Artifact** | Highlight material updates<br>Provide visual aids<br>Provide data analytics<br>Highlight design decision milestones<br>Provide a semi-structure ecology via triggers |
| **Social Structure** | Provide equal opportunities to information and artifacts<br>Strengthen within group communications<br>Assign a coordinator |
| **Evolutionary** | Support continuity of activities<br>Provide a semi-structure ecology via triggers |

Table 2. Implications for design.

#### *5.3.1. Design Implications for the Design of Artifact Ecologies.*

In this section we provide a set of design implications that refer to developing new learning settings or blending heterogeneous artifacts in a shared space for learning and design activities. Interactive surface and space specialists can take into consideration the possibilities and weaknesses of different digital tools in the colorful palette offered by the progress of technology these days. Blending tools with various unique attributes within an ecology for group-work requires the designer an understanding on how to create links or "niches" (Coughlan et al., 2012) between the different devices or worlds (physical or digital).

*Link the physical to the digital space.* An artifact ecology may include both physical and digital environments. As seen in the present study, groups developed sketches and prototypes during the face to face sessions or during individual work at home and shared them on the online platform that represented their digital workspace. This indicated that the physical material that would facilitate the collaborative work were necessary to co-exist within the digital workspace as well. This mechanism created a link between the physical and digital space. In addition to providing an information buffer where groups can select and review information when appropriate, blending the physical with the digital buffer may increase the level of contextual awareness over the group activities. For design teams, the need for contextual awareness  disperse teams we argue that it is valuable to provide a real visualization of the physical workspace within the online buffer.

*Physicalization of digital material.* The groups largely used the projector to project the digitally captured material on their physical workspace, commenting and annotating it on the physical space. In this sense, we understood their need for physicalization of the digitally captured material, where physical representations of data can help the group to explore and communicate data easier, since design work is relying highly in the physical world (i.e. pen and paper). The concept combines the ideas from other domains such as visualization and tangibles, but suggests a new understanding and means for the propagation of information.

*Provide equal opportunities to information and artifacts.* Within the artifact ecology, the groups worked around the table with ease and direct access to all the provided tools within the artifact ecology. However, the tabletop projection was operated by one group member at a time, while the rest of the group queued for their thoughts to be heard and considered for the primary task. Thus, technologies that allow the whole group to interact with the main task are encouraged to avoid traffic in communication channels towards the individual handling the technology; providing multiple points or forms of interactions at the same time and equality in manipulating information. In collaborative design activities, the equal access to information relates to access to design material and user research, where they can be accessible from multiple points.

*Provide Information Transformation Means.* For the groups to successfully share information and material developed during their project, the use of transformation tools, i.e. tools that merge physical with digital objects, is necessary. For example, individuals used mobile devices quickly to capture a sketch of a prototype from the physical paper and share it with the rest of the group. In another instance, textual information was transformed to verbal that allowed a greater distribution of information around the group. Thus, an artifact ecology for collaborative activities should provide multiple ways of converting information between and within tools for the group to review. Such a feature can be achieved by including transformative means within the artifact ecology; that is ways that information can be transformed from one form to another. Besides mobile devices that can help individuals capture information through photos, audio, and video recordings, we further suggest additional mechanisms and tools to be included in the artifact ecology that will support the transformation of verbal information to textual and vice-versa.

Moreover, visualized material eased information flow in the group, especially during review and recall of related information discussed in previous sessions. More specifically, written discussions and decision-making milestones were more quickly reviewed and understood than audios recordings. Thus, the use of automation mechanisms will transform and allow group members to replay information files in other forms, decreasing the cognitive needs of the group to a minimum and allowing each member to process information in the most preferred form.

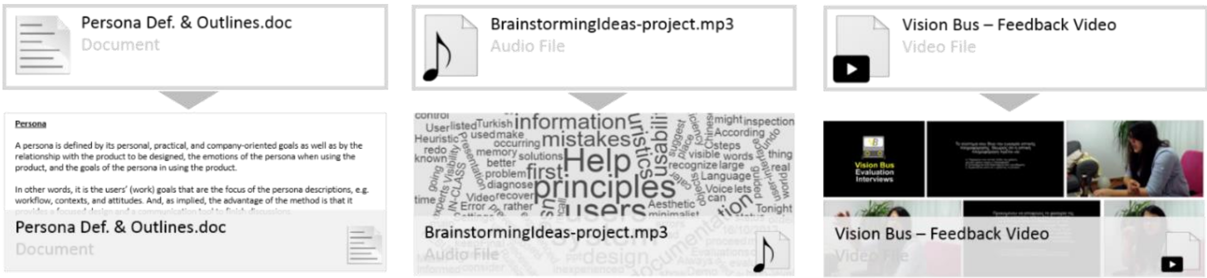



Figure 4: An example of visualizing the contents of (a) text, (b) audio and (c) video files as a post on Facebook group.

More specifically, such an online communication and coordination tool can provide the ability to group members to personalize their own way of presenting the group content by selecting among different ways of automatic transformation means:

(a) raw data content, a method suggested for the representation of the raw content of a text file as seen in Figure 4 – (a),
(b) summative representation of raw data, such as a word cloud of more ideal for audio files to summarize the content such as Figure 4 – (b), and
(c) snapshots of raw content, ideal for video material in order to provoke an immediate recognition through the different snapshots without the need to review the whole content as visualized in Figure 4 – (c).

Besides Facebook, these transformations could also be useful in other similar tools such as Google Classroom or Workplace (by Facebook).

*Increase proximity of interaction through awareness.* In an ecology with multiple participants and devices, a central focus point allows the group to collaborate during the task at hand. Providing a central focus point within the horizon of observation for all group members can increase the distribution of awareness concerning the task at hand during the collaborative work. As design activities are located within the intimate space of an individual (Fischer & Hornecker, 2012), the location of the rest of the group members within the personal space (within 1.2m) allowed them to smoothly observe each other's activities. In the current case, the group was located around a rectangular table (< 2m) that allowed group members to overhear discussions from any point around the table as well as check the progress of design materials. However, expanding the workspace in a room size setting, hearing each other's conversations and being aware of each other's design activities can be problematic. In the case of larger teams and workspaces, where collaboration is spread across several locations, either collocated or not, one can display the design activities in location A in a discreet representation in location B and vice versa as seen in Figure 5.

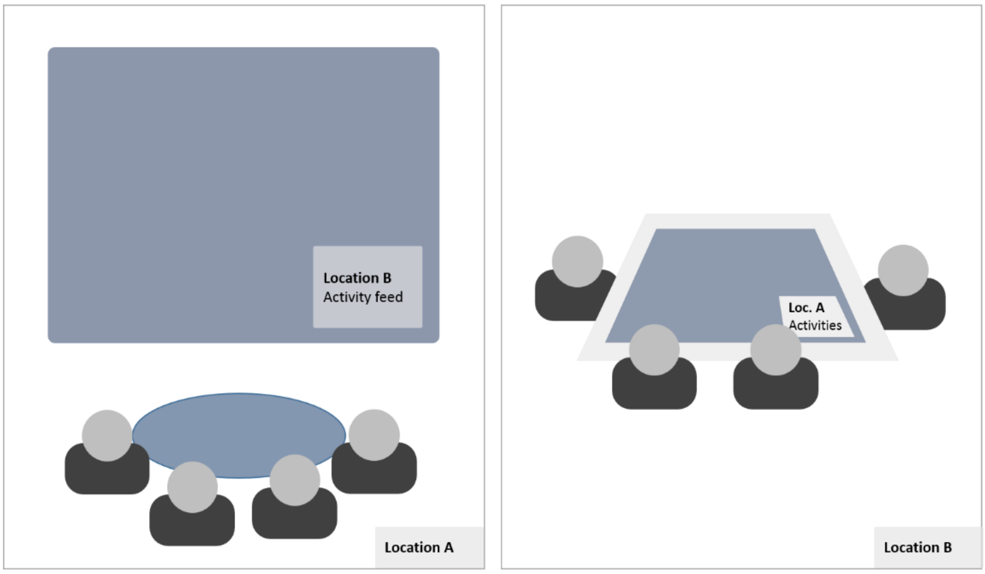



Figure 5: Creating proximity in disperse teams through awareness of activities

*Provide visual aids.* In order to allow groups to collaborate successfully and coordinate their activities visual aids should be in both the physical and the digital space of the artifact ecology. For example, the groups used extensively the triggering points given by the tutors during the lecture, representing the tasks and materials that can help them complete each phase of their work. Representing the lecture objectives and general triggering points in the physical space provides a tangible goal that the group needs achieve.

*Provide a semi-structured ecology via triggers.* One of the issues that two out of the six investigated groups faced, was the emergence of an extremely active leader that largely influenced the activities and decisions of the group. As observed though, the groups reacted positively to directional hints and triggering points provided in the lecture on how to proceed, and further used them to scaffold their activities. Thus, we argue that a process of triggering group members can improve the scaffolding of their online and physical space. For example, triggering members to provide different thoughts, alternative solutions and ideas could encourage other members to participate actively in the group work. While a member shared an idea during the brainstorming session the online tool, in this case Facebook group, can notify group members in a more proactive way (Reeve, 2013) such as “Member X contributed this idea. What is your perspective on it?” or even prepare default answers on the comment section that the group member must fill in and post. Furthermore, building on the previous design consideration of visualized decision points on group’s timeline, at the moment of creating a decision milestone the system could trigger an agreement poll for the members to express their beliefs. However, embracing the hints and triggers may also rely on the group’s need for structure.

### *5.3.2. Design Implications For Individual Artifacts*

For technology designers and educational technologists, this work provides an exploration of how different physical and digital tools available in the market can be incorporated in an artifact ecology and be appropriated to support collaborative learning activities. The analysis also revealed design implications on how individual artifacts can contribute in distributing cognition during co-located and online interactions, and thus support collaboration and coordination, with some of implications already incorporated in project management tools (highlighting material updates and decision milestones).

*Support continuity of activities.* As a means of coordination, Facebook kept the timeline of the collaborative activities, retaining a record of shared material, discussions and decisions. Allowing visual continuity and links between the different activities in a timely order is important during reflection over design and evaluation cycles. For groups to review their project activities and compare it to the design process, they need to explore their actions visually in the order that were posted. Alternatively, the interface can also provide links between the different activities regarding the group activities' phase.

*Highlight material updates.* Group members must be notified of new content and activity within the online platform as was emphasized in (Parmaxi, Zaphiris & Ioannou, 2016). Yet, notifications might not be enough. New posts, comments on existing posts and updated material should be highlighted within the online platform without affecting the timeline of activities as described in the evolutionary model description. In design conversations the timeline of activities and progress of design work and decisions are crucial. Thus, group members should be able to quickly identify the updated material and recent activity in a distinct section as a whole through a quick scan, such as a notice board on top of the timeline.

*Highlight design decision milestones.* Facebook also provided the ability to capture and share ideas, resources, snapshots and then brainstorm, discuss and reflect below them – directly linking their conversations to the material. Often the group would go back through their comments and posts to review whole discussions to recall information and final decision of a design concept or element. The time-consuming scan could have been avoided if the group had the ability to differentiate the decision post from the rest of the brainstorming and reflection posts. Furthermore, decision-making points could be further visualized in the timeline of the group work to map important points of their project. Highlighting design milestones within the timeline of activities could be represented as life milestones are represented in an individual's Facebook timeline as seen in Figure 6 - Left. Another example of highlighting decision milestones without disrupting the timeline of activities could be by including a vertical time ruler, visually representing decisions as milestones as seen in Figure 6 - Right.

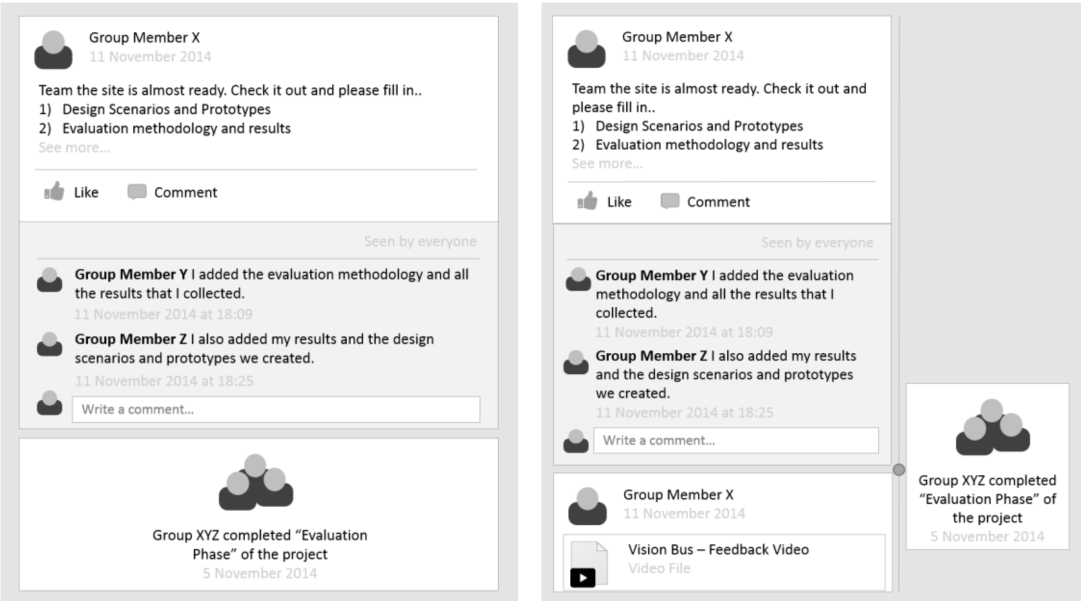



Figure 6: Left: Project decisions represented as group milestones within the timeline. Right: Project decisions represented within a different column of the group activities.

*Provide data analytics.* By reviewing the Facebook group content and timeline of groups we identified several instances of posts tracking the status of specific tasks, specific group member's progress and workload. Thus the ability to automatically analyze group data can benefit the group work by reducing the posts on the online environment and in result the "continuous scrolling". Progress tracking can be implemented on design tasks, providing starting point, current status and potential deadline.

### *5.3.3. Design Implications for Instructional Designers*

The rich narrations provided in previous sections not only allow us to suggest how to appropriate tools and space for collaborative activities but also provide some valuable insights into the roles of learners, tutors, and artifacts. Thus instructional designers and practitioners can use the valuable insights this work provides and transfer observations and outcomes into future research and practice.

*Strengthen within group communications.* Through the analysis of the social structure of the six groups, we observed that privacy and access to information by all group members and tutors was in some cases problematic. Establishing smaller, private circles of communication within the group, which are stronger than the overall group communication, may lead to the division of the collective cognition of the group. For example, when two members discussed repeatedly project tasks and issues, and then reporting and reflecting upon them during the face-to-face sessions with the whole group, would hinder the continuity of group discussions and decisions. Thus, tutors should discourage the creation of circles of privacy within the group. However, as mentioned by Group 2 (Class 1), the observation of the online platform by tutors stressed the group members to provide verified material and communicate formally. Thus, tools that facilitate online sharing and communication should allow the group members to exclude others (e.g different roles) to view the posted content, strengthening the within group communication.

*Assign a coordinator.* What emerged as important in the social roles and responsibilities was the role of the coordinator; an individual pushing for deadlines, meetings, deliverables and responsibilities while also orchestrating communications. Such a feature could be realized by encouraging students to assign the role of the coordinator to a group member from the beginning of the project. However, with the progress of technology the role of the coordinator would be ideal for an artificial intelligence agent as part of the ecology; gathering groups' attention around an activity, and reminding them about deadlines of the course or self-enforced by the group.

## 6. Discussion

This paper adds to the knowledge of the HCI community by building on the understanding of how groups behave and use artifact ecologies as a shared space for collaborative work. Through this investigation, we unpacked the potentials and limitations of artifacts as part of an artifact ecology for collaborative design work. We provided a detailed and empirical based description set of design implications that directly affect the design of individual artifacts, and the way educational technologists implement artifact ecologies or shared spaces for collaborative activities. Within the following section, we will interrogate the additional contributions of this paper, by reflecting on the design implications we extracted from the descriptive narrations and the benefits of a DiCoT analysis.

### *6.1. Design Implications for Artifact Ecologies for Design Activities*

Whilst such technological spaces have shown the potential for supporting collaborative activities, deciding what principles to follow for designing such a space has been proven difficult and challenging. Building on foundational literature on awareness (Gross, 2013), this work reveals a different way that the purpose and performance of various devices can fluctuate each time based on the settings and activities under investigation. Given these challenges and shifts in how each artifact is performing in a given artifact ecology configuration, the context and approach to which we try to understand and map their complexities are also constantly changing.

Tom Gross (2013), reviewing research on awareness for cooperative work, suggested the connection between awareness and proximity, which we put to the test in this realistic setting. However, the level of awareness or the approach to implement it can vary. The balance between the design of the physical space and the activities taking place is critical. Within the context of this work, group members were located close to each other, allowing the proximity to assist the distribution of information and knowledge. Thus, in the process of designing the shared space, designers should take into account the collection of activities, the level of proximity that they would require, so that the feeling or illusion of proximity should be retained.

Järvelä et al. (2015) proposed the externalization of individuals learning process to regulate awareness during collaborative learning in shared spaces. Similarly, in our work we specify the design implications for awareness with exemplars for the current context. Considering both literature and our findings, we suggested the use of visual aids and data analytics as mediums to externalize an individuals contributions in the collaborative activities, implications already known in the field of cooperative work. However, this work has proven that such behavior can be helpful in the case of collaborative design activities, as on a micro level, the individuals benefit from externalizing and capturing a creatively vague process. Furthermore, in terms of the configuration of the set-up the proximity between artifacts people, all located within the personal space of the individual, can raise the contextual awareness of a group's actions in the collocated space.

On its basis, technology performs the role of the mediator to achieve a particular goal, by reflecting our cognitive abilities to the real world (Peschl & Fundneider, 2014). In this sense, the proposed design implications of "highlight material updates" and "highlight decision milestones", play the role of a guide, associating the shared space to our mental model of work. Based on Lee's et al. (2012) work, visualizing information can reduce the amount of cognitive load required by an individual to process the information available and perform an associated task. Thus visualizing updates and milestones in a physical or digital workspace can reduce the amount of processing needed by an individual to become up to date with the collaborative activities.

In addition to enriching existing and established design principles, the current study proposes both novel and known design implications applicable for collaborative design activities, for shared spaces with both physical and digital elements. For example, "providing transformation means" in an artifact ecology can increase the sense of freedom. This level of freedom can allow group members to receive and comprehend project information and material in the form of their preference. We, therefore, find the notion of "freedom of expression" as proposed by Lee et al. (2012) a relevant form of thinking, extending it towards a "freedom of understanding means" in a ‘design-for-all’ aspect.

### *6.2.DiCoT as a toolkit for artifact ecologies*

Earlier we discussed how the different technologies available now at our fingertips can provoke new challenges on designing artifact ecologies. We also indicated the potential benefits of employing DCog to understand the strengths and weaknesses of an artifact ecology intended to support collaborative learning activities. Through these in-class investigations, this work illustrated the utility of DCog and DiCoT as a tool for modelling interactions and interdependencies during collaborative learning activities in an artifact ecology. The rich data set allowed us to provide descriptive accounts and a pathway on how to examine a methodological tool in a new context, not previously tested.

Describing the artifact ecology as a whole system through DiCoT, helped us understand the behavior of groups and the mechanisms they adopted to appropriate the artifact ecology for their work. The use of all five models of DiCoT allowed a comprehensive review of the system from different perspectives and a rich set of design implications. As see in Table 3, both artifact and social models are the origins for the majority of design implications in the current setting. This exposes the need for the design of artifact ecologies that support collaborative design activities to accommodate the demands and expectations of users as individuals as well as a social group. Thus, an in-the-wild DiCoT investigation of technology set-ups in complex socio-technical environments such as an artifact ecology for collaborative design activities can help the researchers explain individuals' and groups' behavior and communicate to the rest of the community implications on the design of artifact ecologies. However, the particular affordances of the physical and digital artifacts that compose the artifact ecology need to be specified. The design of an artifact ecology for collaborative activities should not be reduced to either purely technological innovation or cognitive processes. Thus, DiCoT served as an ideal framework to introduce new domains for future investigation but failed to provide specific recommendations on how to resolve specific issues.

As the second research question of this work is to evaluate the usefulness of DiCoT as a toolkit for understanding artifact ecologies, we perceive the given design implications as the criteria for this critique. The DiCoT model provided a set of design implications, including both ecological aspects and independent behaviors for the configuration. However, analyzing the complex system from an ecological lens with DiCoT, we would expect a more enriching or enlightening view of the ecology as a space. Combining both the design structure from contextual design and the cognitive principles from distributed cognition theory was undoubtedly beneficial for the applicability of the framework on the analysis of data. However, to some extent the use of the five models and their principles felt too rigid to go beyond the complexities of new technologies, possibly excluding important information for new design implications.

### *6.3.Limitations*

However, the design of artifacts and artifact ecologies always involves a wide range of aspects that should be considered (Peschl & Fundneider, 2014). For this investigation, designing with the context and activities in mind was central for the practical contributions of this work. Thus, one of the limitations of the present study is the use of a particular user group and setting that led us to extract context-specific design guidelines. To increase the transferability of our findings we described the characteristics of the participants, the setting, and the collaborative activities thoroughly. For instance, the context and events taking place in the artifact ecology are similar to collaborative work environments of product design teams working towards the solution of a real-world problem, using similar technical equipment to support their efforts.

In addition, the context and activities could be partially transferable to technology enhanced learning settings where collaborative work is encouraged. Thus, we are encouraged that the design implications of our findings can be transferred and applied in similar settings always based on the judgment of the researcher or practitioner, contributing on technical aspects of artifact ecologies in work and education settings. We make no claim that our setting is a realistic workspace, but it can approximate one, and an outside researcher can decide whether the findings of our work might apply to real workspace configurations.

## 7. Conclusion

In this study, heterogeneous off-the-shelf tools have been put together, constructing an artifact ecology to support collaborative design work. Following the structure and theoretical background of DiCoT, we analyze groups' collaborative behavior and summarize them through the five narrative models of DiCoT. The rich understanding constructed through the analysis allowed us to consider design aspects of artifact ecologies as shared spaces for design activities. Furthermore, the design implications that emerged from this work can spark fruitful discussions around the specific design of artifacts such as social networking tools and how they can be effectively blended within an artifact ecology. Through this work, we also provide evidence on the use of DiCoT as a different approach for supporting the evaluation and re-design of such environments across spatial, informational, artefactual, social, and evolutionary aspects.

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