CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF FINE AND APPLIED ARTS

Doctoral Dissertation

A DISTRIBUTED COGNITION PERSPECTIVE FOR COLLABORATION AND COORDINATION: ARTIFACT ECOLOGIES IN DESIGN STUDIES

Christina Vasiliou

Limassol, April 2017

CYPRUS UNIVERSITY OF TECHNOLOGY

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DEPARTMENT OF MULTIMEDIA AND GRAPHIC ARTS

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Approval Form

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Cyprus University of Technology

Limassol, April 2017

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ABSTRACT

The evolving nature of technology has brought new possibilities to the design of technology-rich learning environments for collaborative activities. The experience of a user is spread across devices, across physical or digital spaces or in-between face-to face sessions, building up to the necessity to consider the collection of devices as a whole interactive space. The design of "micro-interactions" remains important, but there is a bigger issue we need to consider. How can interaction designers construct efficient artifact ecologies for collaborative activities? To this aim we need to acquire an in-depth understanding of the complex interactions and interdependencies between collaborators and information technologies.

Through a multi-phase design approach, this dissertation focused on understanding within-group interactions during collaborative learning activities in an artifact ecology. This dissertation consists of four phases, three sequential phases to collect and analyse data, and one integration phase. The first phase explored the use of physical and digital tools in an HCI course and the role of an artifact ecology in supporting collaboration and coordination around design tasks. The second phase aimed to transfer and apply the DiCoT methodological framework into a classroom setting towards building an understanding of collaboration and coordination in terms of physical arrangements, communication channels and mediating artifacts. The third phase addressed the social and evolutionary aspects of the artifact ecology and proposed an expansion for two models of the DiCoT framework. Finally, the fourth phase integrated findings from previous phases to provide design implications on how to construct classroom artifact ecologies and to address how DiCoT can be used as a methodological toolkit in classroom artifact ecologies. The dissertation concludes with practical guidelines and implications for practitioners and researchers on designing technological tools and set ups for the support of collaborative design activities in classroom settings.

Keywords: distributed cognition, artifact ecology, collaboration space, HCI education.

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LIST OF ABBREVIATIONS

HCI: Human Computer Interaction TEL: Technology Enhanced

Learning CSCL: Computer Supported Collaborative Learning

CSCW: Computer Supported Cooperative Work DC: Distributed

Cognition

DiCoT: Distributed Cognition for Teamwork CD:

Contextual Design

CI: Contextual Inquiry

PBL: Problem-Based Learning

UbiComp: Ubiquitous Computing

UCD: User Centered Design

MD: Multiphase Design

F2f: Face to Face

3D: Three Dimensional

M: Mean

N: Number

SD: Standard Deviation

1 Introduction

This chapter introduces and reviews the background, motive, and scope of this doctoral dissertation. We discuss relevant research, which led to a set of research questions, as well as the research design and actions taken to address the specific research questions. The chapter concludes with the structure and outline of the dissertation.

1.1 Introduction to Designing Artifact Ecologies for Collaboration

As technology progresses, ubiquitous computing, once envisioned by Weiser (1991), is now partially a reality. The evolving nature of technology has brought new possibilities to the design of technology-rich environments for collaborative learning activities. As we blend tablets and smartphones with personal computers in our everyday lives, we are no longer limited in front of a single screen, at work or home, during formal or informal learning activities. These technologies communicate and share information with each other creating an internal network, an ecology of artifacts (Jung, Stolterman, Ryan, Thompson, & Siegel, 2008; Bødker & Klokmose, 2011). Further, Loke and Ling (2004) explained that these heterogeneous technologies are interlinked as a unified system. In the case of collaborative environments, group members may work together tackling the same problem as well as work individually on sub-tasks. Digital and physical artifacts within the artifacts ecology may be used for a variety of tasks while each individual may perform an activity differently. This flexibility in activities and interactions, creates endless possibilities and design considerations for the construction of an artifact ecology for collaborative activities.

Salomon (1992) claimed that the development and integration of new technologies in an environment cannot be studied independently of its surroundings. To design effective technology-rich environments we need to acquire an in-depth understanding of the complex relations and interactions between collaborators and information technologies. As Resnick (1996) indicated, to provide useful technological tools we need to understand learners' experiences, the domain knowledge, and the computational paradigms and interdependencies. Furthermore, HCI researchers highlighted the need to prototype and understand complex technological set-ups in-the-wild (Crabtree, et al., 2013). The fundamental concept behind "in the wild" investigations is to understand

how people behave and appropriate technologies based on their preferences and context (Rogers, 2012).

However, traditional evaluation methodologies are unable to reflect the unpredictability of a real-world context and capture the complex interactions (Rogers et al., 2007) that a multi-tool and multi-participant environment encloses. In the areas of HCI and computer supported cooperative work (CSCW), researchers identified Distributed Cognition (DC) as a powerful tool for understanding the interdependencies between users, tools, and tasks (Halverson, 2002). DC recognizes that a collaborative activity takes place across individuals, tools, and external and internal representations, as a unified cognitive system (Zhang & Patel, 2006). The added benefit of examining a complex collaborative system through DC is that it allows researchers to take a step back and see the "whole picture," focusing on actions and interactions central to the coordination of work activities (Rogers, 1992). Such an understanding will allow researchers and practitioners to determine where changes should or should not occur in the system as a whole.

Designing and appropriating a technological set-up such as an artifact ecology to support collaboration between individuals brings up new challenges. More specifically, bringing together people with different background and expertise raises concerns over the design of the tools and interactions in the artifact ecology. To understand complex socio-technical environments, that is, environments with multiple tools and participants, it is crucial to acquire a rigorous and exhaustive analysis plan. DC on its own does not enclose an established methodology for collaborative learning/working environments. In this work, the DiCoT methodological framework (Blandford & Furniss, 2005) was considered ideal for constructing this understanding for student-groups working collaboratively on a design task within an artifact ecology. CSCW research has used DiCoT extensively, providing the necessary structure for data collection, analysis, and interpretation. In this work, we present in-class investigations of student groups during collaborative learning activities in an artifact ecology within an HCI classroom. Within the scope of this dissertation DiCoT was used to analyse students' behaviour to understand the interactions and interdependencies in the environment, between learners, tools, and the internal and external representations that the shared space provided.

1.2 Research Focus

In this work we focus on understanding and documenting learner-learner and learner artifact interactions in a classroom artifact ecology from a DC perspective. More specifically, this work had two overarching goals:

(A) Propose design implications for researchers and practitioners for constructing efficient classroom artifact ecologies.

(B) Transfer and assess DiCoT as a toolkit for understanding learner-learner and learner-artifact interactions in a classroom artifact ecology.

A multiphase mixed-method design was adopted to address the overarching goals of this study which were broken down to specific research questions and iteration of connected quantitative and qualitative studies.

1.3 Research Design and Research Questions

A multiphase mixed-method design (MD) is a mixed-method approach that allows a researcher to examine a topic through an iteration of connected quantitative and qualitative studies, with each new iteration building on the previous one. MD provides a high degree of freedom in the design of each iteration which might sequentially or concurrently blend both qualitative and quantitative data collection and analysis procedures.

Within the MD research design, this dissertation consists of four phases in total, including three sequential phases to collect and analyse data, and one integration phase to incorporate and re-examine data from previous phases to extract practical implications. Based on the overarching goals of the study, a set of research questions was formulated, which were addressed in the four phases. More particularly, each phase includes two sub-research questions addressing each one of the two overarching aims of this dissertation.

- Phase 1 served as a pilot study for exploring the use of physical and digital tools in a Human Computer Interaction (HCI) course and the role of an artifact ecology in supporting collaboration and coordination around design tasks

[RQ1.A]. Phase 1 also explored whether the DiCoT methodology could be used in a classroom setting [RQ1.B].

- Phase 2 aimed to transfer and apply the DiCoT methodological framework into a classroom setting towards building an understanding of collaboration and coordination within a classroom artifact ecology. More particularly, the phase aimed to reveal the physical, communication, and artifact attributes of the artifact ecology based on DiCoT [RQ2.A] and to explore how DiCoT can explain the interactions between learners and artifacts [RQ2.B].
- Phase 3 focused on addressing the social and evolutionary aspects of the artifact ecology [RQ3.A] and proposing an expansion of the DiCoT framework [RQ3.B].
- Phase 4 aimed to integrate the findings from previous phases and provide design implications that emerge for constructing classroom artifact ecologies [RQ4.A], as well as to address how DiCoT can be used as a methodological toolkit to understand learner-learner and learner-artifact interactions in classroom artifact ecologies [RQ4.B].

Figure 1 presents a schematic representation of the research questions as they are spread across the four phases and two tracks of our investigation.

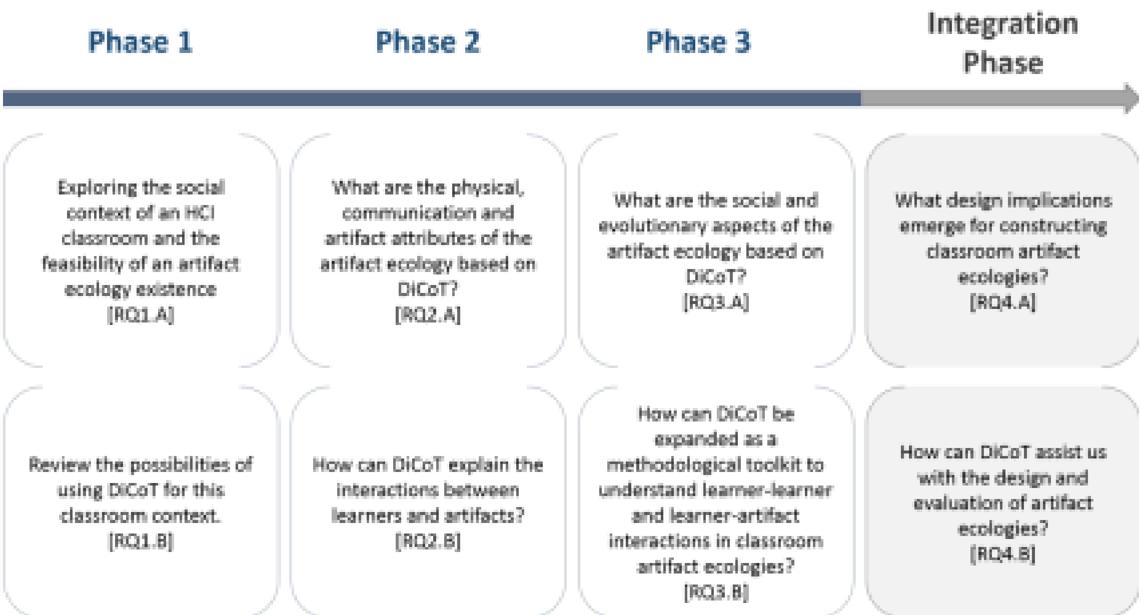

Figure 1: Research questions as divided across the four phases of this dissertation

1.4 Research Context

The present study ran in three classes throughout 2012-2014 to capture a broad spectrum of the use of an artifact ecology in a number of groups as seen in Figure 2. The classes were related to human-computer interaction and presented practical and real-world exemplars of user-centred design (UCD) process for the design of a product. Following a Problem-Based Learning (PBL) approach, the classes met face-to-face once weekly for 3 hours for 13 weeks. In-class activities involved a mini-lecture to provide UCD methods and exemplars and a two-hour practical session to apply the UCD process on a given group project. Between the weekly sessions, the group kept collaborating on the group project as it was a major deliverable of the course. UCD activities involved three phases: analysis, design, and evaluation over the course of the semester. These activities involved understanding of target audience and requirements for the product, developing the conceptual design of their product through storyboards, personas, and prototypes, and evaluating and revising the high-fidelity prototype of their product.

Phase 1

Phase 2

Phase 3

Phase 4

Figure 2: Four phases of this dissertation as associated to the HCI classes where data collection occurred.

Even though our analysis involves collaborative learning activities in a classroom artifact ecology, the focus of this work is entirely on identifying patterns of collaboration and coordination to propose design implications. The learning outcomes of the collaborative activities are outside the scope of this work. We make the assumption that following an already established pedagogy (Problem-Based Learning) suggests that learning would occur within the classroom setting.

For the purpose of this work the classroom space was turned into an artifact ecology, using affordable, off-the-shelf technologies. The enriched learning space aimed to support student collaborative activity, particularly brainstorming, researching, reporting or reflecting, both in-class and in distance (in-between the face-to-face sessions). Furthermore, the artifact ecology together with the PBL approach aimed to promote openness and flexibility by allowing group members to use the provided equipment as they perceived appropriate. There were four identical settings to allow four individual groups working at the same time. The artifact ecology employed three primary characteristics:

- A tabletop projection, physically gathering the group around a central focus point.
- Facebook private groups for each group to view and share material and information about the project.
- A collection of different kinds of mobile devices, including iPods, smartphones, and tablets, to support concurrent activities and mobility of participants.

However, the boundaries of our analysis is within the students' in-class activities and online communication through the Facebook platform as the students allowed us to observe. Other mediums of communication were also used by teams between the face to-face meetings (e.g. phone calls, google hangouts once a week) but were outside the observation limits of this work.

1.5 Significance of this Work

The added benefit of examining a complex system through the lens of DC is that it allows researchers to take a step backwards and see the big picture, focusing on interactions and actions central to the coordination of work activities. Such an understanding allows researchers and practitioners to pinpoint where changes should occur or should not occur in the cognitive system as a whole. However, the practical and applied DiCoT methodological framework has been explicitly used in the workspace, with no known application to a collaborative learning setting. One important contribution of this work is that it provided evidence for the transferability and applicability of DiCoT from workspace to classroom environments, which adds to the validity and replicability of this practical DC toolkit.

Both social and evolutionary aspects of DiCoT are still underdeveloped and are not considered along the primary dimensions for a DiCoT analysis (Blandford & Furniss, 2005). However, literature highlighted social and cultural-historical aspects important and necessary for the understanding of complex, multi-tool and multi-participant environments. An important contribution of this work is that of strengthening the DiCoT social and evolutionary models with new principles based on empirical data. Such an expansion may allow the researchers to consider design implications that may impact the aspects of the system, which previously had been neglected, and help explain social and evolutionary values of the artifact ecology.

Furthermore, this work can provide practical implications and unique insights through the deep narration of collaborative behaviour in classroom artifact ecologies. More specifically, interface and interaction designers as well as instructional designers, may draw relevant information from this dissertation on the use of technological and physical tools (projectors, tables, mobile devices) for the design and development of artifact ecologies that can ease the distribution of cognition in co-located and dispersed team working environments. Furthermore, this work also provides insights into the roles of learners, tutors and artifacts which can be transferred to future research and practice.

1.6 Structure of the Dissertation

The current dissertation is structure into seven chapters, in addition to this introduction:

- Chapter 2: *Literature Review*. This chapter showcases empirical work on artifact ecologies and their role in classroom environments including HCI education and PBL settings. This chapter also reviews theories and tools employed to understand complex socio-technical systems and provides a holistic view of DiCoT and its implementations in various contexts.

- Chapter 3: *Research Design*. This chapter reports on the research design and the different phases of data collection and analysis involved in this dissertation.

- Chapter 4: *Exploring Artifact ecologies in HCI Education (Phase 1)*. This chapter presents the exploration of artifact ecologies in the context of a postgraduate HCI course. A mixed-method approach was employed to evaluate their collaborative experiences and reveal affordances of the physical and digital tools in their interactions.

- Chapter 5: *Applying DiCoT from Workspace to Classroom Settings (Phase 2)*. This chapter showcases the transfer and application of DiCoT methodological framework in a different setting. Using DiCoT framework we analysed the behaviour and interactions of four groups of learners to (i) allow an in-depth understanding of the interactions among learners and tools during collaborative activities and (ii) provide insights on how the affordances of the artifact ecology supported collaboration and coordination.
- Chapter 6: *Expanding DiCoT's Social and Evolutionary Models (Phase 3)*. This chapter reports on the third phase of this dissertation, which uses the DiCoT framework to study collaboration and communication patterns, physical movement and social structures of two groups of learners working on a design problem as they evolve over a 3-month period.
- Chapter 7: *Integrating findings moving from Narrations to Design Guidelines (Phase 4)*. This chapter reports on the fourth and final phase of this dissertation, that integrates the data collected from Phase 2 and Phase 3 to provide summative narrations of each one of the five models of DiCoT and extract design implications.
- Chapter 8 – *Discussion*. This chapter discusses the findings of the different phases of this research work providing deep insights into the learner-learner and learner artifact interactions evident in the artifact ecology as well as implications of this work for interaction designers and instructional designers.

2 Literature Review

This chapter introduces and reviews the relevant literature on investigations with artifact ecologies and shared spaces, theories and tools used to analyse collaborative interactions in collaborative technical environments. By reviewing recent research conducted in the field of artifact ecologies, shared spaces, and ubiquitous computing (UbiComp), we describe the spectrum of technologies and methodologies used and provide a holistic view of the field. In addition, we review the theoretical background used in this investigation (DiCoT – distributed cognition) and its principles and contributions in the analysis of complex socio-technical systems.

2.1 Introduction

A growing body of HCI work aims to explore methodologies and tools that allow researchers to understand existing UbiComp systems – that is interactive systems that are expanded towards the user's surroundings making the interactions "pervasive" (Weiser, 1991) - and improve the design of technological spaces, physical or digital. Vicente and Rasmussen (1992) indicated that in the design of such spaces, the aim of the researcher is to support a user's direct perception, creating an ecological technological environment that "maps the intended invariants of the functional system design onto the interface." Working in different fields ranging from applications in education (Poole et al., 2011; Díaz, Sicilia & Aedo, 2002), workspace (Chin, Wang, Zhu, Xu, & Wang, 2011), healthcare (Furniss & Blandford, 2010) and domestic settings (Lee & Šabanović, 2013), researchers focused on understanding human-artifact interactions to propose or revise technological solutions. While ubiquitous computing evolves, interactions are distributed across different devices and displays with a variety of capabilities, features, and characteristics. As Bødker and Klokmose (2011) described, such an environment represents an "artifact ecology", a space rich in technologies that co-exist and share information with each other. Chamberlain and his colleagues (Chamberlain et al., 2012) highlighted a paradigm shift in approaches to design and develop these spaces. Considering naturalness for users' behaviour, researchers "turn to the wild," (Rogers, 2012) to understand how people behave and appropriate technologies in different contexts.

Under the notion of "ubiquitous computing", many researchers have explored tools and theories to analyse, understand and model users in complex socio-technical systems. For example, situated action theory is often applied to analyse and interpret the complexity of interactions between individuals and their surroundings through a social lens (Button & Dourish, 1996). What is often highlighted within literature is the unstructured way to apply this theory. Activity Theory, on the other hand, offers a set of concepts that researchers use to map onto features of real-world settings providing a cultural historical perspective (Kaptelinin & Nardi, 1997). Similarly, Distributed Cognition provides a theoretical framework to interpret collaborative environments involving multiple people and technologies (Rogers & Ellis, 1994). However, even though the theoretical approaches play a significant role in the work of practitioners, there is a general applicability difficulty (Rogers, 2004). The complexity of these theories allows practitioners to interpret and apply them as they perceive appropriate in real-world and "messy" settings. Such a mechanism is largely based on subjective interpretations decreasing the uniformity of the procedures followed to analyze and explain raw data.

Researchers have therefore been working on transforming theories into methodological frameworks with clearer guidelines for practitioners. Such approaches were constructed on the basis of cognitive science and the concepts of situated action, ecological and distributed cognition (Hutchins, 1995). For example, Kaptelinin, Nardi, and Macaulay's (1999) work delivers the activity checklist, a structural approach to applying activity theory. More recently, DiCoT was developed to provide clear associations between the data and the theory through five models: physical layout, information flow, artifacts, social and evolutionary models (Blandford & Furniss, 2005; Furniss & Blandford, 2010). A detailed and rigorous analysis plan is crucial to understand and interpret complex socio-technical environments. We can obtain this rich understanding by studying a user in its natural settings to propose design implications for the technology in need. As recent work in HCI highlighted, we need to prototype and understand complex technological set-ups in-the-wild (Crabtree et al., 2013), where interactions and behaviour of users is realistic and not controlled.

This chapter presents a review of the main directions that shared spaces research has been driven in recent years. The review is divided in four parts: part one covers research around artifact ecologies and shared spaces; part two addresses the literature related to

the context of this dissertation, an HCI classroom following a PBL approach; part three reviews existing evaluation approaches and tools that researchers employed to understand interactions in UbiComp systems; part four discusses the DiCoT tool selected for our investigation, its existing state and previous works that validate or expand its principles and applicability in different contexts.

2.2 Empirical Work on Artifact Ecologies

2.2.1 The Concept of Artifacts

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. In the connection between the artifact and the user, Bødker and Klokmose (2011) also introduced the concept of the mediator. For instance, a browser is the mediator as the user browses the internet for a particular task. A well-constructed mediator allows its users to focus on the artifact of their interest and perform their mission successfully. An ill-structured mediator can cause breakdowns drawing user's attention away from the artifact in use. Thus the quality of mediation relies on the transparency and seamlessness of the mediator, which reduces the breakdowns in communication between the user and the artifact. As an artifact becomes transparent and seamless during an interaction, the user considers it as part of its body. Therefore, to aid the design of interactive artifacts, we need to reflect on the level of transparency it may provide in a cultural context. With the progress of technology, artifacts become more interactive, and autonomous, augmenting everyday settings into ubiquitous computing spaces. Jung et al. (2008) suggested that HCI designers and researchers should investigate the pervasive nature of digital artifacts, taking a philosophical stance concerning their cultural properties and values.

2.2.2 Origin of the Concept of Artifact Ecologies

Ellis, Gibbs, and Rein (1991) defined the concept of shared spaces as an environment where individuals and artifacts interact and collaborate. More specifically, the term

'spaces' represents the notion 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 (Price & Rogers, 2004; Martinez-Maldonado, Clayphan, Ackad & Kay, 2014), 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 (2011) 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 (see Figure 3).

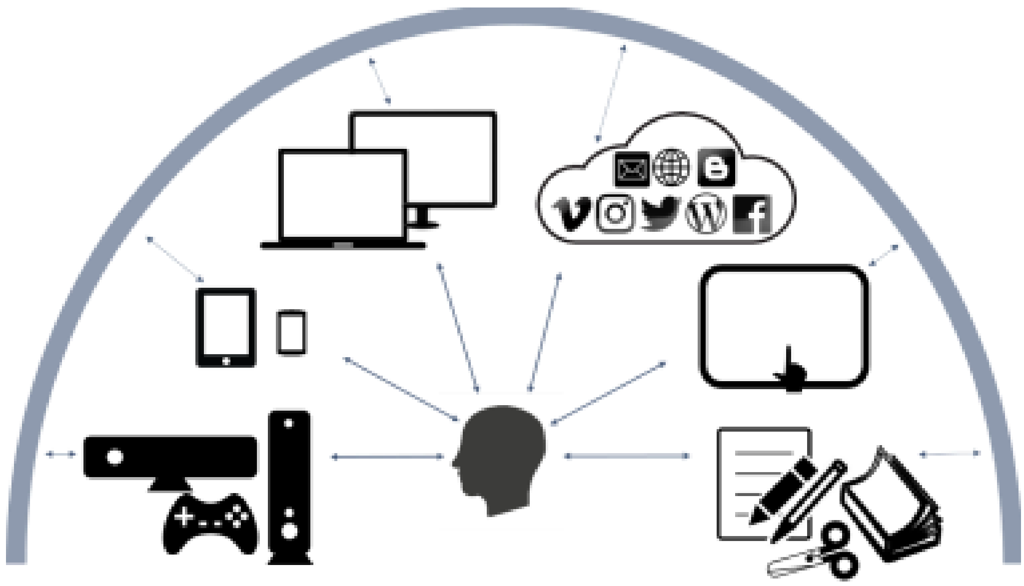

Figure 3: Artifacts as surroundings of an individual connected as a unified system

An artifact ecology can incorporate various artifacts that support the same objective using different approaches or attributes. However, the choice of what to use, when and in what way relies on the individual using the artifact ecology each time. In addition, the selection of the artifact relies equally on the situation and activity that the individual

faces, and what was their intention. Digital and physical artifacts are never used in isolation, and thus we need to consider their surroundings to understand their use. As Bødker and Klokmose (2011) indicated, durability, social connotations, aesthetics, and longevity are some of the aspects that exist in different variations across artifacts. Furthermore, since an artifact ecology offers multiple artifacts that can support the same purposes, individuals may use them in sequence or parallel, creating overlapping events and activities and increasing the complexity of interactions. In their investigation, Jung et al. (2006) demonstrated that artifacts in such an environment are interconnected, highlighting that how an individual uses an artifact may impact the way other artifacts may be used in the artifact ecology. Considering the level of interrelations and interdependencies that exist between artifacts, there are endless possibilities and design considerations for the construction of an artifact ecology for collaborative activities.

2.2.3 Artifact Ecologies in Collaborative Settings

Working in different fields ranging from applications in education (Poole et al., 2011; Díaz, Sicilia, & Aedo, 2002), 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. In this section, the review focused on collaboration in artifact ecologies, device ecologies, and multi-device spaces, as they have been deployed in learning and work settings. Furthermore, we reflected on the impact of the design attributes of individual artifacts on the performance of the group within the ecology and the challenges that arise in the understanding of collaborative activities in artifact ecologies.

2.2.3.1 Artifact Ecologies in Collaborative Work

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 this uncertainty, Huang, Mynatt, and Trimble (2006) explored how to orchestrate teamwork in complex systems using a blend of projections, screens, and interactive displays. Based on their observations, the collaboration style and tasks of the group changed over time, increasing the difficulty to simulate a multi-device ecology entirely.

Widening the unit of analysis of the artifact ecology, researchers have also explored industrial settings such as hotel and healthcare facilities, to understand how the full collection of artifacts can impact the collaboration of the staff. For example, considering a hotel, its staff, and their equipment as a unified system, Cabeza and Kaptelinin (2013) explored how two technological changes can influence the current communication and coordination mechanisms. Following an ethnographic investigation, the researchers investigated how the hotel staff re-appropriate the technology provided individually as well as a group. Switching the context towards a hospital unit, Dawson et al. (2008)

considered personal computers, mobile devices, and wireless network as the artifact ecology. The authors propose a conceptual framework on how to understand the ecology on two levels - device-level and user-level community - highlighting the importance of the link between the two. Laying technologies next to each other even though not planned to work together, will lead to the creation of a wider cognitive system. Thus the collection of artifacts, their set-up, and attributes are tightly interwoven with the performance of the system as a whole.

2.2.3.2 Artifact Ecologies in Collaborative Learning

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., 2017a). More particularly, the "Out There and In

Here" (OTIH) space was designed to support collaboration during a geoscience course, involving the coordination of two groups – one in class and one in the field in real time (Coughlan et al., 2012) (Adams et al., 2011). The classroom team combined tabletops, large screen displays, and tablets, to research and provide spatial information to the field group, coordinating the site search. Combining multiple interactive tabletops, microphones, an interactive whiteboard and an orchestration desk for the teacher, Mercier et al. (2012) explored the use of interactive surfaces in classroom learning. The ability to project tabletop activities on the whiteboard aided the joint understanding through distributing cognition, triggered fruitful discussions of the whole class and assisted the progress of the groups. However, the authors revealed concerns regarding the physical layout of the classroom and how the arrangement of interactive artifacts within the ecology can impact the collaborative interactions.

While researchers study the use of various technologies and tools in learning activities, a concern often raised is the way to orchestrate the technologies and activities, and balance communication and learning. While in early years, orchestration reflected the process of coordinating interventions during learning activities (Fischer & Dillenbourg, 2006), later the term mirrored the management of resources - the internet, media - across different locations (classroom, home, online) (Dillenbourg et al., 2009). For example, GLUE!-PS is a system developed to orchestrate heterogeneous resources such as Web 2.0 tools and virtual learning environments (Prieto et al., 2014). Focusing on supporting teachers' role, researchers also suggested scripting (Rodríguez-Triana et al., 2015), learning analytics (Martinez-Maldonado et al., 2017b), and real-time assessment instruments for collaborative classroom interactions. For instance, Chounta and Avouris (2016) propose the integration of a real-time rater on the quality of collaboration. The proposed instrument supported teachers in identifying anomalies in the collaborative activities, improving the practice of teaching staff. In another case, Slotta, Tissenbaum and Lui (2013) combine the learning analytics in a smart classroom space, that combines multiple workstations, smartphones, interactive and visualisation screens. The teacher managed the students experience in the technology-rich space by observing their activities through a "teacher tablet" that incorporated real-time updates of all students and activities in the collaborative space.

Reviewing relevant work on artifact ecologies in collaborative learning, we see researchers appropriating the design of the artifact ecology by taking into consideration the people, whether teenagers or university students, and activities involved to accommodate their objective. For example, Pantidi, Robinson, and Rogers (2008) augmented a library area with projector, large shared screen, whiteboard, personal computers and game consoles. The D-Space was intended to provide a space for creativity in learning and teaching and allow the exploration and sharing of knowledge. However, observations revealed that users often whispered or “created corners” when multiple individuals or groups were occupying the shared space. Furthermore, even though guidelines were provided on how to use the technologies, the teams did not take full advantage of the complete collection of artifacts provided, revealing a gap between the ways designers expect an artifact ecology to be used from its actual use. Designing for an open learning space, where the learners and activities are not specified prior to the design of the group raised the need to understand how individual artifacts can support or hinder collaboration within an artifact ecology.

2.2.3.3 Understanding the Impact of Artifact's Design

While addressing artifact ecologies as a joint cognitive system based on empirical works in different settings, the design of individual artifacts can define the broad range of possibilities the ecology can support. Thus researchers also attempted to explore how different artifacts behave and what activities they can assist in the artifact ecology. More notably, researchers used either in-the-wild investigations and 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. The researchers compared low-tech and high-tech settings, including interactive tabletops and walls, and revealed concerns and design issues on how each setting supported or hindered equal participation. Other researchers also compared horizontal and vertical displays, focusing on how they support collaboration (Rogers & Lindley, 2004) and what is the impact of size or angle on the muscle tension (Al-Megren, et al., 2015).

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, Wigdor et al. (2007) explored hypotheses concerning various parameters in an interactive display – such as angle, position, slope, area - and their impact on an individual's touch accuracy. Similarly, 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. Marshall, Rogers and Pantidi (2011) focused on the use of interactive tabletop in a tourist information centre. This allowed researchers to observe and reveal differences between how an interactive tabletop can provoke interactions in a public space and how the artifact performs in a multi-user investigation. 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).

2.2.3.4 Challenges in Understanding Artifact Ecologies

Whilst such technological spaces have shown the potential for supporting collaborative activities, deciding what design principles to follow for designing such a space has proven more difficult. In a real world setting, collaborative activities entail group members working together with a particular goal in mind, running several tasks at the same time and each group member performing a task in a different way or tool. To design effective collaborative learning environments we need to acquire a deep understanding of the complex relations and interactions between collaborators and information technologies. As Huang et al. (2006) highlighted, projections, screens, and interactive displays have clear interdependencies within an ecology, although not designed as a unified system. When devices are studied individually, researchers revealed that shared surfaces are suitable for collocated activities (Scott, Grant, & Mandryk, 2003), interactive tabletops promote equal participation (Marshall et al., 2008), and mobile devices support access to information and mobility (Perry et al., 2001). However, Looi, Wong and Song (2012) stressed the importance of what affordances or constraints different technologies such as mobile devices can bring to a

technology-rich environment. It is therefore, crucial to understand what each one of these technologies brings to the collaboration and coordination of group-work.

Designing and appropriating a technological set-up such as an artifact ecology to support collaboration between individuals brings 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 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.

As Crabtree et al. (2006) indicated, ubiquitous systems and digitally enhanced spaces increase the mobility of users and the distribution of interactions across different applications, devices, and displays of various capabilities and characteristics. Chamberlain et al. (2012) highlighted the paradigm shift in the approaches to design and develop technologies. In an attempt to understand the impact of technological intervention in a natural context, researchers move out of laboratories and conduct research "in the wild." The fundamental concept behind "in the wild" investigations is to understand how people behave and appropriate technologies based on their preferences and context (Rogers, 2012). Such investigations involve observing and recording what people do and how this changes over time. Such approaches are ideal to understand interactions in digitally enhanced spaces and artifact ecologies. For example, Coughlan et al. (2012) demonstrated the user foci analysis method, an analysis of user focal-points through video frames of users' interactions to study patterns and transitions between devices in a learning ecology. Furthermore, recent work in HCI highlighted the need to prototype and understand complex technological set-ups in-the-wild (Crabtree, et al., 2013). More recently, a number of workshops have stressed the importance of both in-situ design and evaluation approaches for multi-device and multi-participant spaces (Houben et al., 2015; Houben et al, 2016).

2.3 Empirical Work on Technology Use in a PBL-HCI classroom

This work focuses on an HCI classroom in higher education, which follows a PBL structure. We therefore need to understand how the technology will impact the structure and activities of a course as well as the learning and engagement of students. In this section we present the review of how technology augmented HCI and PBL classrooms.

2.3.1 HCI Education and Orientation towards Real-World Problems

As a domain of research, Human Computer Interaction involves the study interactions between human and computer. It is regarded as a challenging and multidisciplinary field, integrating computer science, design, and engineering as well as social and psychological aspects. In 1994, a report on new directions in HCI education emerged (Strong et al., 1994), where Strong along with several HCI contributors defined the primary objectives that a student must achieve in an HCI course. However, there is an ongoing debate among HCI researchers on the topics that represent the HCI domain (Churchill, Bowser, & Preece, 2013).

A significant and complex aspect of HCI education was to enhance the experience of collaborative design and development, especially in the context of complex and realistic problems. A panel discussion in 1997 examined the essentials in HCI education highlighting the weakness in HCI community for consensus over the content of HCI Education and how it should be delivered (Sears et al., 1997). The panellists further identified the need for practical relevance in the tasks, realistic experience, and working collaboratively in groups towards the solution of a problem. But as indicated earlier (Strong et al., 1994), one of the challenges of teaching HCI, besides its multidisciplinary form, is that of "setting up a practical context and approach for getting students involved in real world projects".

Studies addressing issues in HCI education were sporadically reported. HCI instructors and tutors adopted teaching approaches and techniques as seen in other closely related disciplines, such as design and architecture. As demonstrated early by Deborah Hix (1990), a typical HCI course consists of lectures and labs, an engaging group project, and smaller individual assignments. Projects and assignments, combined with mid-term and final exams formed the basis of students' evaluation. Reviewing recent work in HCI

education, we identified that profoundly addressed issues were the need for release of creativity, and the need for having practical problems for students resolve. HCI educators have explored techniques to increase creativity in their classrooms (Kotzé & Purgathofer, 2009; Fonseca, Jorge, Gomes, Gonçalves, & Vala, 2009), focusing mainly on increasing the time spent in idea generation in a creative design process. In an investigation of the challenging field of HCI education, Aberg (2010) further indicated that among the issues faced, was the lack of engagement among students, which wrongly perceived the context of HCI as something trivial. Lazem (2016) further highlighted that students in engineering and computing underestimate the importance of HCI education due to the way it is often integrated into their courses. The investigation urged the need for a more drastic approach.

In 1990, Winograd (1990) suggested the exploration of the design studio as a teaching approach in HCI education, considering the need to embrace design and creativity. More specifically, the design studio approach consists of group projects on real-world problems, critique sessions for reflection, and specially designed rooms. Since then, a number of studies in HCI education have been using the studio design, as a teaching approach adapted to HCI from architecture and design schools (Reimer & Douglas, 2003). For example, a study by Reimer and Douglas (2003) redesigned an HCI course based on the studio concept with the hypothesis that the new design would be improved. Students positively reacted to this new approach and particularly appreciated teamwork and the context of "learning by doing". Another study, reported challenges of adopting the studio approach in HCI while providing valuable feedback for instructors on how to promote students' creativity (Cennamo et al., 2011). As the authors indicated, even though the studio gives the impression of a promising approach, it focuses entirely on improving creativity, hindering other aspects equally important to HCI education.

Differentiating the target of enhancing creativity, researchers also focused on embracing the necessity for tasks in a realistic context. As it was clearly outlined by Strong (1995), "a result of working on a large-scale, real-world project, (is that) students are expected to acquire skills critical to successful interface design and implementation". In particular, a study included professionals and employed a service learning approach, providing the benefit of seeing the outcomes of your work in real-world contexts (Mankoff, 2006). Students were more motivated than before, but the researcher

highlighted issues related on how to distinguish the roles of professionals and the tutor, and how to reduce the instructors' workload.

In an attempt to resolve to provide structure in the HCI classroom, researchers employed constructivist models such as problem-based and case-based approaches. As

Prince and Felder (2006) indicate, in the context of computer and engineering education constructivist methods, that is methods where students are actively involved in the construction of knowledge and learning, are equal or more effective than traditional teaching methods. The authors further highlight the four common attributes of these pedagogical approaches that contribute to their effectiveness in teaching: learner centred, that refers to the emphasis given on students responsibility for their own learning, constructivist, that relates to the concept of students creating an artifact as their sense of learning, collaborative, that refers to the need for students to work in groups, and active learning, that relates to the need to discuss issues raised and tackle problems as they arise. Exploring the potential benefits of such approaches in HCI, Vat (2001) demonstrated the ability of a constructivist model to satisfy the needs of HCI education, however focusing on theory. In a transfer from theory to practice, McCrickard, Cheware, and Somervell (2004) studied three types of case methods marking PBL and decision-making approaches as the most effective regarding students' interest towards learning. In a more recent study, an HCI workshop was entirely designed based on PBL with positive effects (Koutsabasis & Vosinakis, 2012) lending support to the aim of this research to develop an entire HCI course based on PBL. This perspective has brought new lines for investigating the compatibility of PBL and HCI in higher education situated in a multimodal information space.

2.3.2 Technology Use in HCI Education

The use of technology in HCI courses emerged by the need to demonstrate its use to enhance students' technological skills, while the ability to draw peoples' attention was one of the reasons that technology was given such an important role. Since then, HCI instructors and researchers have made several attempts on delivering HCI courses, learning workshops, and tutorials using technology to support students' learning and engagement.

One of the first forms of technology that appeared in HCI courses and is still thriving today is online learning, from online communication and sharing tools, to fully online courses (HCI on Coursera, n.d.). Brush et al. (2002) explored the use of online communication tools to interact and share thoughts, comparing the type of tools that better support students. The study revealed that even though the online tool was beneficial, the groups preferred reflecting and completing their online discussions in class, highlighting the need for face-to-face interactions and hands-on activities. In addition, HCI educators also used online environments with the support of multimedia and games in their classrooms. For instance, Brereton, Donovan, and Viller (2003) employed a video card game, to foster the development of observational skills. The authors instructed the students to capture video material and review snapshots in a game-like manner to discuss their field notes, demonstrating that the use of multimedia can engage students towards learning. Furthermore, the study of Zaharias, Belk, and Samaras (2012) developed a class scenery with the support of a virtual world, but the engaging environment attracted too much of students' attention, drawing their focus away from learning objectives.

Nevertheless, HCI researchers have also explored the use of blended learning in the HCI and interaction design education, mixing digital tools in the classroom. In particular, a case study developed information spaces with the aim of engaging students in conversations beneficial for the practice of design (Fields, Barbill, & Jones, 2010). The information space included both digital and traditional elements, such as projections, pen, and paper. The merger of the physical and digital worlds was also explored by another study on building a new learning ecology to enhance the design experience of students (Faiola & Matei, 2010). More particularly, the researchers highlighted that the use of mobile technologies could contribute to a product design cycle for HCI students, supporting them to understand how to design and development new products or applications considering previous mental models of users. Findings from both studies indicate that enhancing the classroom space of HCI students with digital elements can provide the practical orientation suggested by HCI community, opening new directories in HCI education research.

2.3.3 Technology Use in PBL Classroom

Focusing on the need for a hands-on orientation and real-world problems in an HCI classroom, the current research used PBL as the pedagogical approach for the HCI course. Reviewing technology employed to deliver a PBL course was thus considered essential for the progress of this dissertation, as the use of technology in HCI education was only sporadically reported. Hence our investigation focused on recent studies to reveal the most appropriate use of technology in PBL to enhance students learning in real-world problems in HCI, design, engineering and related classrooms and learning environments.

A review of PBL research and practice by Hung, Jonassen, and Liu (2008) discussed that the use of technology in PBL follows two primary directions. The first direction relates to the combination of PBL with e-learning (i.e., online and blended forms for PBL). In this case, the Internet is used to offer better access to resources, while instructors suggest the use of web environments for the organization of PBL courses. For online PBL, researchers have used several forms of synchronous and asynchronous communication tools to enhance PBL practice; from simple forums and wikis (Ioannou, Brown, & Artino, 2015) to custom-made instruments such as LdShake (Hernández-Leo et al., 2011), e-Forum (ChanLin, Chen, & Chan, 2009), eSTEP (Hmelo-Silver & Chernobilsky, 2004), or STELLAR (Derry, Hmelo-Silver, Nagarajan, Chernobilsky, & Beitzel, 2006) among others. Real-time communication tools were appreciated comparing to asynchronous communication tools, due to the direct type of communication (Lo, 2009). Authors explained that real-time communication simulated physical interaction and immediate feedback of real world. An evolution of the blended form of PBL is the Flipped Classroom, with researchers exploring the feasibility and benefits of a flipped PBL class over PBL and more traditional structures (Tsai, Shen, & Lu, 2015).

The second direction of the use of technology in PBL contexts involves the use of multimedia. Multimedia supported learning environments have been proven to attract students' attention and increase engagement towards learning (Liu, Toprac, & Yuen, 2009; Liu, Olmanson, Horton, & Toprac, 2011). A few studies have focused on understanding gaming elements that might lead to improvements in students' engagement. For example, Echeverri and Sadler (2011) examined the use of gaming settings in PBL courses with encouraging results regarding knowledge gains and student motivation. Warren et al. (2012) studied games with the aim of identifying gaming elements to facilitate the redesigning process of a PBL course and increase students' engagement. Others suggest that immersive virtual worlds are necessary for PBL as they allow learners to practice and master skills without real-world consequences (Savin-Baden, 2011; Warren et al., 2012). For example, Parson and Bignell (2011) studied the use of Second Life in an undergraduate psychology course where students communicated with avatars to identify the family's characteristics in solving a case problem. Students reported higher levels of engagement in the module and felt that the new form of digital presence was valuable and encouraging in acquiring knowledge. Researchers have also employed virtual worlds in computing and design courses such as "Introduction to Information Technology" using ActiveWorlds (Omale et al., 2009), "Computer Programming" using Second Life (Esteves, Fonseca, Morgado, & Martins, 2009), or HCI using Second Life (Zaharias et al., 2012) and OpenSimulator (Vosinakis, Koutsabasis, & Zaharias, 2011) . Outcomes indicated that virtual worlds offered a fun and engaging approach towards learning, while the increased level of reality regarding activities in a simulated environment improved their motivation.

Apart from these two principal directions of technology use in PBL (Hung et al., 2008), we further explore how other technologies seem to provide support for different aspects of PBL, such as problem-solving and reflection. In fact, a few researchers from various fields of engineering, design, and education have created and examined different technologies in problem-solving learning environments, stressing the importance of understanding their affordances or constraints and how they can contribute to a learning environment (Looi et al., 2012). For example, researchers used a surface as a central focus for the collaborative activities of learners, however having different attributes in each study. For instance, Bardill et al. (2010) employed a downward-pointing projector to boost creative conversations while Hilliges et al. (2007) used vertical and horizontal interactive displays to support coordination during problem-solving. In a study by Bridges, Botelho, and Tsang (2010), the researchers included an Interactive Whiteboard to raise the levels of learning and engagement. Furthermore, mobile technologies have also been proven helpful during PBL (Holzinger, Nischelwitzer, & Meisenberger, 2005), from assisting the self-directed learning of students to structuring group interactions during PBL sessions (Hendry, Wiggins, & Anderson, 2016). It is, therefore, possible that a technology-rich space, where multiple everyday technologies co-exist, will result in a wider cognitive system (Huang et al., 2006) where PBL processes and outcomes are empowered.

2.4 Analysing Collaborative Interactions

The primary aim of this work is to understand the interactions evident in a classroom artifact ecology during group-work on a design task. We define these interactions as the two-way effect that occurs between two or more individuals or tools. The focus of this work is to analyse these learner-learner and learner-artifact interactions and how they support collaboration and coordination during group-work on a design task. However, we first have to understand what this work identifies and perceives as interactions, collaboration, and coordination and what analytical approaches and techniques researchers use to understand interactions in collaborative settings.

2.4.1 Collaborative and Coordinating Interactions

In general, the term collaboration refers to the act of two or more people working together for a common outcome (Bannon & Schmidt, 1989). In the learning sciences, it is stressed that the collaboration is tightly interwoven with the construction of knowledge and the level of engagement of all group members (Lipponen, 2002). As stated by Roschelle and Teasley (1995, p. 70) collaboration "is the result of a continued attempt to construct and maintain a shared conception of a problem". Definitions of the term collaboration however, are not precise about specific parameters of a collaborative activity such as the number of people working together, the time span or location of the activity (co-located or distant). In the context of this dissertation, the term collaboration is used to refer to both co-located and distant settings involving small groups of five to six users, synchronously collaborating towards the solution of an open-ended design problem over a period of three months.

Regarding coordination, we all have an instinctive understanding of what it symbolises. We understand it as a harmonious organization and completion of tasks. Malone (1988) defines coordination as “the additional information processing performed when multiple, connected actors pursue goals that a single actor pursuing the same goals

would not perform.” Computer supported cooperative work (CSCW) systems aim to sustain and reduce the workload of the team from these coordination mechanisms (Andersen, Carstensen, & Nielsen, 2002). The degree to which the coordination mechanisms are supported or fully automated by the computer system vary. Some empirical studies showcase the seamless and harmonious coordination performed by co located individuals (Heath, Jirotka, Luff, & Hindmarsh, 1994) as well as the issues raised for the inadequacy of oral interaction on complex cooperative work (Schmidt & Simonee, 1996). When designing CSCW systems with the aim of improving coordination, a researcher focuses on reducing the workload of coordination tasks. Waving coordination issues off oral interactions, allows individuals to focus on physical or digital artifacts and representations in the computer-supported environment.

The focus of this dissertation is to understand these two way interactions between a learner and an artifact or between learners. This understanding will aid in improving the productivity and satisfaction of the learning experience of the team by creating a computer supported collaborative learning environment that enhances both collaboration and coordination.

2.4.2 Analytical Approaches: Theories and Perspectives

Researchers have employed different concepts, theories and perspectives to map and interpret interactions during collaboration and coordination through technology. This section examines in more detail how recent theoretical developments in HCI have contributed to the analysis and understanding of human-computer interactions and collaborative behaviour. More specifically, we looked at how researchers have attempted to use these theories to understand human behaviour in conjunction with technology and how they have contributed to developing and evaluating technologies. More particularly, my review focused on theoretical perspectives with an ecological consideration of interactions, such as activity theory, situated action, ecological psychology, distributed cognition, and embodied interaction (as seen in Figure 4).

Cognition

Embodied Interaction

Theories & Perspectives

Situated Action

Activity Theory

Ecological Psychology

Distributed

Figure 4: Theoretical perspectives considered for the analysis of collaboration and coordination

2.4.2.1 Activity Theory

Activity Theory is a theoretical approach applied in HCI that focuses on the analysis of interactions concerning an activity (Kaptelinin & Nardi, 1997). As a conceptual framework, it provides a cultural and historical description of actions and interactions within a given environment. In its original context, researchers used Activity Theory to explain cultural practices as they occur in their context, naming them as "activities". Activity Theory provides a hierarchical model that links individuals, tools, and outcomes. Such an analysis may inform the design of technology that better fits individuals in their work space (Bødker & Bannon, 1991). One of the widely used extensions of Activity Theory is Engeström's work (1990). His framework suggests additional concepts such as community and division of labour to leverage the analysis of work contexts. The extended set of ideas provided a more robust approach to matching the concepts to instances in the data. This high adoption rate of Activity Theory was also part of the checklists and tutorials Kaptelininn, Nardi, and Macaulay (1999) created, making the theory readily applicable by practitioners.

Activity Theory has been adapted and applied to a diversity of fields, particularly technology, education and workspace (Rogers, 2012). Activity Theory's contributions to the HCI field centre on the fact that it provides a structured framework that breaks down an activity into a set of concepts that can then be mapped onto features of real-world settings. For example, Fjeld et al. (2002) demonstrate how an activity-centric approach

can shape the design of a teamwork software. As researchers indicated, applying activity theory allowed them to structure and articulate their design practices contributing to an improved design of their groupware interface. More recently, Pena Ayala, Sossa, and Mendez (2014) demonstrated how Activity Theory might be useful to develop an adaptive e-learning system. Their focus was on the evolutionary aspect of anticipation, defined as the motive of the activity that allows us to predict future events. The authors highlight that the use of the anticipation principle regarding each activity to scaffold the learning artifacts and material allowed higher levels of students' learning. Blin and Munro (2008) on the other hand focused on using Activity Theory as a lens to explain technology adoption and disruption in teaching practices. Using Engeström's Activity Theory triangle, the authors explored functionalities of a Virtual Learning Environment that hinder an institution-wide uptake. Even though Activity Theory and its extensions have been used as useful heuristic tools, Kaptelinin and Nardi (2006) highlighted the difficulty for practitioners to adopt Activity Theory in the design process.

2.4.2.2 Situated Action

One of the most well-known methods of bringing new ideas in technology use and system design through a social lens is situated action (Suchman, 1987). The situated action approach offers detailed accounts of how individuals use technology in real world situations, often revealing gaps with the intended way a tool was designed to be used. Socially-oriented concepts of "situatedness" and "context" are brought to the front of conceptualizing and developing new systems and interfaces (Button & Dourish, 1996; Rogers, 2012). To improve existing working practices and propose aspects for re design, researchers delve into the culture of a setting, spending time in the field to capture a context in-depth (Bly, 1997). Researchers in computing (Dourish, 2004a) considered situated action as a helpful theory to break down systems into conceivable units and unveil new areas for further research.

However, researchers have criticized the weakness of situated action to guide practitioners towards abstracting design decisions. For example, Comber, Hoonhout, Van Halteren, Moynihan, and Olivier (2013) combined situated action with contextual inquiry (Beyer & Holtzblatt, 1997) as a methodology to structure data collection and analysis. The researchers developed a “thick” understanding of food practices and

routines, through interviews and field observation. The narrative approach and the structure of contextual inquiry allowed researchers to identify and propose technological solutions to overcome existing issues with food practices in residential settings. One of the most distinguished frameworks to structure the presentation of ethnographic data was developed by Hughes et al. (1997). The “presentation framework for design” was specially designed to guide designers through the confusion of ethnographic data and unblock the path to extracting design guidelines, however still not as widely applicable for practitioners.

2.4.2.3 Ecological Psychology

Taking an ecological perspective, Gibson (1966, 1979) proposed the view that psychology should also consider a human and its surroundings. HCI community adapted his approach and proposed the use of ecological psychology to understand how individuals interact with technology in their environment (Gaver, 1991; Kirsh, 2001). Researchers simplified the concepts of “affordance” and “ecological constraints” that refer to associations between an individual and the representations in their environment and orienting them towards attributes of the technologies at hand that can help people know how to use them (Rogers, 2012). Vicente and Rasmussen (1992) proposed the Ecological Interface Design (EID) approach as the basis for using Gibson’s theory (1979) for the design of tools and technology-rich environments. Even though ecological psychology can largely contribute to the design of the attributes, appearance, and functionality of a tool, the notion of affordance has often been misused in research and practice (Rogers, 2012). Misuses were often related to the lack of rules and guides on how to use and appropriate the concept of affordance with researchers attempting to clarify its definition and provide frameworks that can aid product design processes (Burlamaqui & Dong, 2014).

2.4.2.4 Distributed Cognition

The evolution of cognitive sciences has brought to the forefront the idea that cognition cannot be bounded inside an individual's mind (Hutchins, 1995), but should conjointly consider an individual's surroundings. Distributed Cognition (DC) suggests that cognition must be seen as a more complex mechanism, one that encloses cognitive processes outside one's mind, such as manipulating external objects, transitioning and

transforming information between actors and tools. When these cognitive processes are studied during collaborative human activity we can observe the distribution of cognition from different perspectives: distribution amongst members of the group, distribution across the physical or digital structure of the group workspace and distribution through time and culture. Hollan, Hutchins and Kirsch (2000) emphasized the importance of understanding the distribution of cognitive processes when designing effective human computer interactions.

Researchers in HCI and CSCW communities have identified DC as a helpful lens to examine the interactions and dependencies amongst participants, technologies and activities (Halverson, 2002). Hutchins and Klausen (1996) studied the distribution of cognitive processes among members of a cockpit flight crew. They reviewed the interactions between internal and external representations and the architecture of information propagation in the cognitive system. Through their analysis they could identify patterns in the collaboration and coordination of the cockpit crew. Such understanding is important not only for redesigning existing system designs and practices but also for creating the basis for new technologies. For instance, Nobarany, Haraty and Fisher (2012) employed DC to design a collaborative system to facilitate analytics. The researchers identified cognitive processes that could be used to support users' collaboration from the beginning, in order to design the system accordingly. Researchers have also illustrated the usefulness of DC in analysing collaborative learning with technology (Deitrick et al., 2015), as well as team-working industrial settings (Mangalaraj et al., 2014), to provide a detailed identification of issues with existing work practices and mediating artifacts. In addition, DC allows researchers to highlight what is salient in the design of existing collaborative working systems and practices and indicate aspects that require redesigning (Rogers, 2012).

2.4.2.5 Embodied Interaction

Another concept with a focus on an individual's surroundings is embodiment, first introduced by Dourish (2001), highlighting that it does not only reflect the physical world but rather the participative status of individuals or artifacts in the world. Similarly to Ecological Psychology and Situated Action, embodiment was considered relevant in computer interactions as it allowed researchers to examine the physical and social organization of an environment (Dourish, 2004b). Dourish (2001) proposed embodied

interaction as a lens that can aid researchers to design new technologies or reveal issues in the design of existing ones. For example, researchers investigated physical collaboration in industrial assembly sites using embodied interaction to guide their prototype system design (Fallman, 2003). Reflecting on the notion of embodiment allowed the researchers to incorporate useful services in their prototype and promote an active role of the employers in the physical and social world. Williams, Kabisch, and Dourish (2005) employed embodied interaction as a reflection concept on their observations in a collaborative installation, interpreting participants' interactions with tools as well as with each other. However, the concept is relatively new with researchers still trying to comprehend this turn to embodiment by proposing new approaches and theories on how to operationalize the idea of embodiment. For instance, Klemmer, Hartmann, and Takayama (2006) suggested five themes under the notion of embodied interaction with the aim to inspire designers on how to capture the essence of embodiment in a new or existing technology. The first two themes, "thinking through doing" and "performance", cover the material understanding of an individual, while the other three, "visibility", "risk", and "thickness of practice", represent the need to provide a social context to embodied interaction. The provided design themes have been proposed as an initial taxonomy for off-the-desktop interactions for both evaluation and general understanding for new solutions. However, the degree to which a designer or researcher can use the proposed themes relies on their individual understanding of the original concept of embodiment (Rogers, 2012).

2.4.3 Analytical Approaches: Tools and Methodologies

In this section, we examined in detail how up-to-date methodological instruments and frameworks in HCI have guided the analysis and understanding of collaborative interactions in co-located or blended settings. In particular, we reviewed how researchers have attempted to use approaches such as online interaction analysis, contextual design, proxemics, and gaze analysis (as seen in Figure 5), to structure the analysis of human behaviour in conjunction with technology and how they have contributed to developing and evaluating technologies.

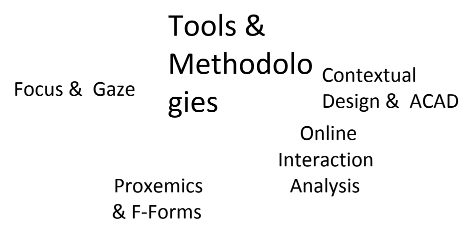

Figure 5: Analytical tools and methodologies used for collocated and blended interactions

2.4.3.1 Online Interaction Analysis

A significant aspect of understanding CSCL activities is the analysis of online interactions. These interactions are performed through various communication and coordination tools that allow logging of events, recording the activities of the user (Kahrimanis, Avouris, & Komis, 2011). A simple example can be discussion boards, where participants can discuss an issue through posting, commenting, and reflecting on each other's thoughts. For example, Song and McNary (2011) analysed students interactions via Blackboard to reveal similarity or variability patterns across students and modules. The analysis of patterns allowed them to suggest that there is no direct association between the level of activity (number of posts) and students' success in the course. Other researchers opt for building a typology of the recorded events, such as OCAF (Object-oriented Collaboration Analysis Framework) (Avouris, Dimitracopoulou, & Komis, 2003); a framework that captures the essence of activities and communication patterns of collaborative activities through chat and a shared online space. As the field was evolving, the need for automatic ways to analyse online interactions emerged. Therefore, researchers put more emphasis on tools and instruments that can aid the work of researchers as well as perform interaction analysis in real-time to support participants and teachers through reflection (Kahrimanis, Avouris, & Komis, 2011).

2.4.3.2 Focus and Gaze Analysis

Focusing on collocated group interactions, researchers have employed video as a tool to record and allow the re-examination of group behaviour for an in-depth analysis. For instance, Coughlan et al. (2012) designed "User Foci Analysis", a method to capture where participants concentrate their focus and how they transfer it from one point to another over a period. The aim of this approach was to understand how groups use and move across different elements in an artifact ecology. Such an approach can be subjective and time-consuming for researchers urging the need for automation. Following this track, in Pfeuffer, Zhang, and Gellersen (2015), the authors present the design of an information display that can track the eye-gaze of multiple participants automatically. The work raised issues regarding trust and privacy regarding sharing gaze information among collaborators, but also opened up new research potentials on how researchers can use such technologies to log gaze information for an automatic mapping and accurate analysis of gaze. Even though researchers have made significant progress in this domain, there is still work necessary to construct a validated tool that would support this.

2.4.3.3 Proximity and Group Formation

Physical location, arrangement, and orientation around a technology can hugely impact the performance of a group and the type of interactions that it can support (Ioannou, Christofi, & Vasiliou, 2013). To structure and guide the way to analyse co-located interactions regarding physical locations, researchers have designed different frameworks on how to explain proximity between individuals or between a technological tool and an individual. For instance, HCI researchers have used the theory of proxemics introduced by Hall (1969) visualized in Figure 6, to study the distances an individual maintains across other people or technology in different settings, proposing the field of proxemic interactions (Ballendat, Marquardt, & Greenberg, 2010; Greenberg, Marquardt, Ballendat, Diaz-Marino, & Wang, 2011). Vogel and Balakrishnan (2004) explored the proxemic zones proposed by Hall (1969) and how they can guide the design of public displays. Besides the novel interaction techniques developed as a reaction to the theory of proxemics, researchers have also focused on creating a toolkit that would help researchers' process proxemics data into meaningful information (Marquardt, Diaz-Marino, Boring, & Greenberg, 2011).

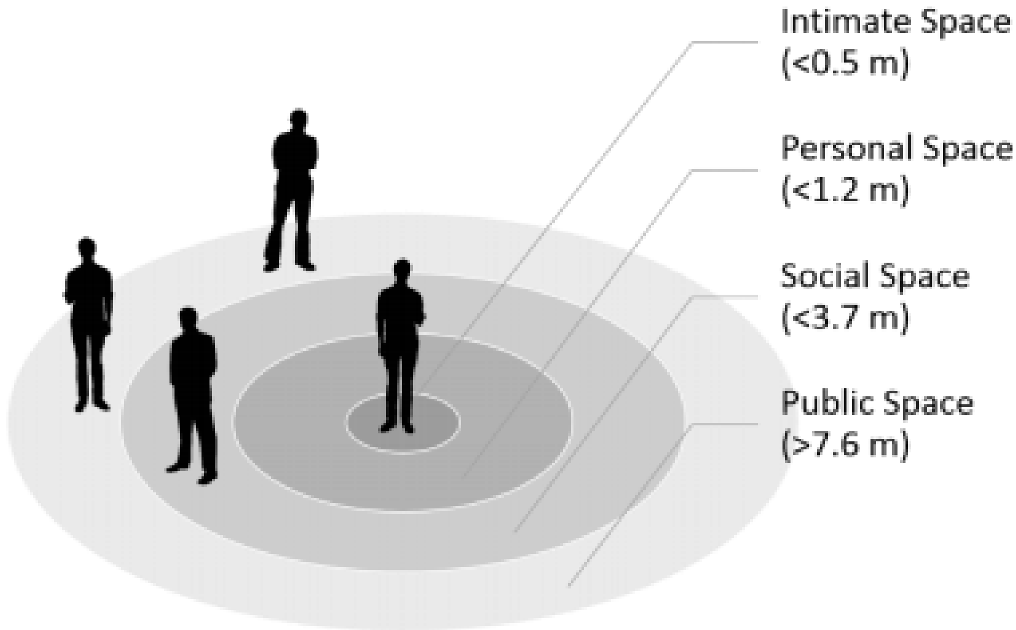

Figure 6: Visualizing Hall's interpersonal distances of an individual, showing radius in meters

Following a more mathematical analysis of the theory of proxemics (Hall, 1969), Kendon introduced the F-formations (1990). As Kendon (1990) defined, "an F formation arises when two or more people sustain a spatial and orientational relationship in which the space between them is one to which they have equal, direct, and exclusive access." Since then, HCI researchers have used the concept to evaluate technological settings. For instance, Marquardt, Kickley, and Greenberg (2012) used F formations to assess the group positions in the GroupTogether system – a cross-device space. Similarly, Marshall et al. (2011) use F-formations to examine spatial patterns of tourists and staff of an information centre to reflect on how can similar information spaces include digital tools. As highlighted by Jungmann, Cox, and Fitzpatrick (2014), F-formations can be used as predictions of spatial behaviour in social interactions, guiding the design considerations of a technological tool or space for co-located interactions.

2.4.3.4 Contextual Design and Activity-Cenred Analysis and Design

To understand and analyse both online and co-located interactions of groups, practitioners have used Contextual Design (CD) in industrial settings and field

investigations. The term Contextual Design 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 (CI), 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). According to the Contextual Design approach: "workflow" involves the way work is divided and coordinated excluding time associations, "sequence" involves the order of work and their association to time, "cultural" maps the influences and links between people in the workspace, "artifact" represents the items people construct or use to accomplish their work, and "physical" visualizes the actual physical environment of the users' workspace. 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 sedentary workplace behaviour. Focusing on collaboration patterns amongst emergency room managers, Randall et al. (2013) followed a more general CD methodology to identify a set of technological requirements and design features. In another instance, Chiou et al. (2014) adopted a contextual design approach to advance the design requirements further, suggesting prototypes for the design of a medication management device used collaboratively by health-care staff. Their work highlighted the contributions of such a data-driven process to reveal less visible aspects of a user's activities such as motivation.

A framework for evaluating collaborative activities in learning contexts is Activity Centred Analysis and Design (ACAD) framework (Goodyear & Carvalho, 2014). Goodyear and Carvalho (2014) provided this framework as a way to understand a multi tool and multi-participant learning environment. The authors suggest that “activity is physically, epistemically and socially situated and mediates outcomes”. The framework suggests three different perspectives that an action should be seen: a) the physical space within which activity takes place as well as the tools that the space includes, b) the social setting, that incorporates the roles and division of labour as seen in Activity Theory, and c) the epistemic setting, that reflects the activities, tasks, and knowledge elements. ACAD can provide a holistic view of group activity through these different components. For instance, Martinez-Maldonado, Goodyear, Kay, Thompson and Carvalho (2016) evaluated a multi-surface setting - including tabletop surfaces, wall mounted displays and handheld devices – using the ACAD framework. The analysis was structured based on the three aspects of ACAD revealing valuable insights into the role of individual artifacts and the role it possessed during the collaborative activities.

2.5 Distributed Cognition for Teamwork

Reviewing analytical approaches, theories, and tools, allowed me to finalize the approach to be followed in this dissertation. This section presents in more detail empirical work on Distributed Cognition and Distributed Cognition for Teamwork as the selected perspective and tool respectively. In particular, we reviewed in-depth empirical work on distributed cognition concerning collaborative settings and technology. Then focusing on DiCoT, we looked at how it emerged, how its structure evolved over time and across different contexts, and reflect on the strengths and challenges that may arise from a DiCoT analysis.

2.5.1 Empirical Work of DC in Collaborative Systems

Distributed Cognition (DC) suggests that cognitive activities are shared amongst people, associated with artifacts and its surroundings and not bounded inside an individual's mind (Hutchins, 1995; Hollan, Hutchins, & Kirsh, 2000) (as seen in Figure 7). It underpins two key arguments: ecological expansion of cognition and embodiment of information in system representations (Hollan, Hutchins, & Kirsh, 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 connected closely with the mechanisms that individuals perform using not only internal information but also knowledge and processes associated with external objects. Compared to theories presented previously, DC allows researchers to highlight what is prominent in the design of existing collaborative working systems and methods and indicate aspects that require redesigning. Furthermore, it gives the researchers a perspective into artifacts as a "box of knowledge and rules" that can simplify the cognitive tasks of a user.

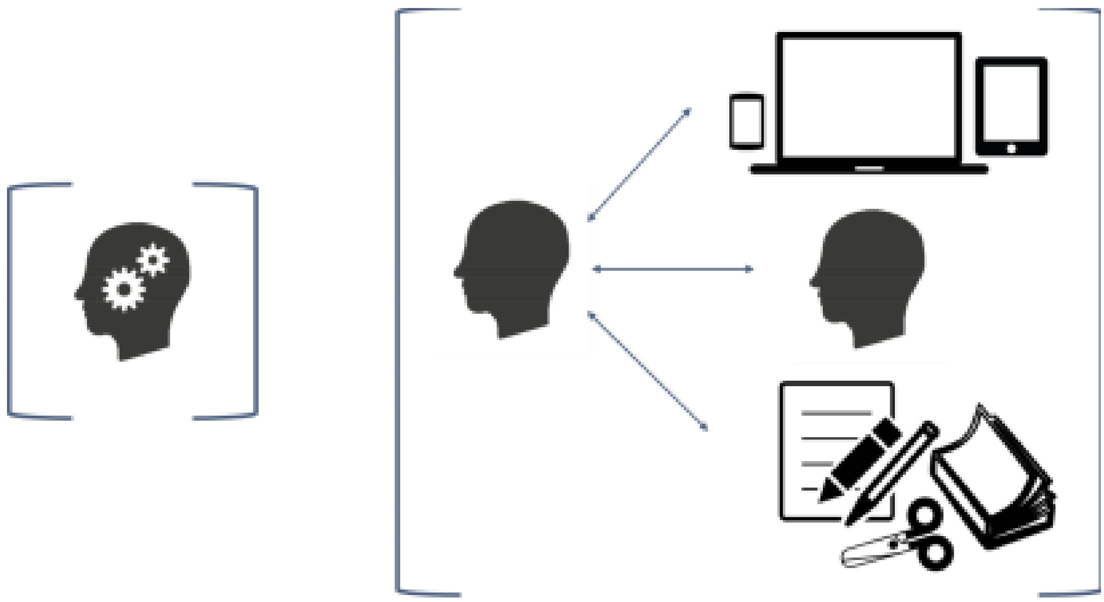

Figure 7: From a traditional cognitive perspective (left) to a distributed cognition perspective (right)

As indicated by Rogers (2012), DC can provide a detailed identification of issues with existing work practices and mediating artifacts. As the author explained, DC 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). This ability to reveal breakdowns in existing practices was considered ideal in the field of emergency and control room contexts due to the increased complexity of the triptych of people, policies, and tools. For instance, following the general idea of “cognition in the wild”, Heath and Luff (1991) described the work practices, communication patterns, and collection of tasks and activities in the London underground control room. The descriptions the authors

provide formed the foundation for the design of technologies that can be augmented seamlessly in the control room with respect to the existing practices. In another case, researchers used distributed cognition in an emergency unit to reveal flaws in the current practices and how to overcome them regarding the team and time organization, space arrangement, and artifact design (Cohen, Blatter, Almeida, Shortliffe, & Patel, 2006). Considering coordination mechanisms and situation awareness, ideas central to DC, Hazlehurst, McMullen, & Gorman (2007) studied open-heart surgery. The analysis helped them identify the different types of communication channels that exist within a surgical context and reflect on how technologies can support their coordination, reducing the cognitive load of practitioners.

As DC allows researchers to grasp the human cognitive capacity and propose revisions or new and design features, it is especially beneficial in healthcare and more particularly the design of medical equipment. For instance, Wu et al. (2008) employed distributed cognition to understand the mechanisms families use to cope with amnesia. Focusing their analysis on how knowledge is accessed and shared, how communication occurs, and how sub-units in the family are coordinated, the researchers propose design implications on how to develop and improve assisting technologies for family communication and awareness. As Hazlehurst et al. (2007) emphasized, by examining human performance in healthcare via a DC perspective, researchers can contribute to the design and improvement of medical technology. Focusing the DC analysis on a particular tool in the healthcare domain, Rajkomar and Blandford (2012a) track how it supports or hinders the distribution of cognition and propose improvements in the design of the artifact that could potentially increase the efficiency of medical personnel interactions.

DC was also used as an analytical tool in learning contexts. For instance, Deitrick et al. (2015) draw on DC theory to demonstrate a detailed 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. Another study focused on the design of a learning artifact, reflecting on how different functionalities supported the distribution of cognition and knowledge (Gomez, Schieble, Curwood, & Hassett, 2010). The study concluded with design implications on tools that can assist instructors for the

education of pre-service teachers as well as aid the reflection of pre-service teachers in their practices. Similarly, Pence, Williams, and Belford (2015) employed distributed cognition to reveal issues in the design of mobiles and virtual reality in relation to chemistry classrooms. Thus following a distributed perspective of cognition can allow researchers to consider all factors relevant to human activity, and how different artifacts in the environment can provide external representations that aid cognition, coordination and collaboration.

The various research studies indicated that researchers used DC to analyse human collaborative behaviour on different levels; from the conceptual level of developing products with the ideas of DC in mind to examining in-depth the existing practices to discover breakdowns and design implications. Through Hutchins' perspective (1995), representations may evolve over time; from the representations that each artifact provides, to the representations as appropriated by the users. The socio-cultural view of technology as a mediator should also be a top priority in the design of interactive systems. However, Rogers (2012) revealed that even though practitioners appreciate the role of theoretical approaches such as situated action theory, in practice they are too difficult to apply. More particularly they indicate that the difficulty lies in the way to implement these theoretical approaches. Providing structure in such complex theories and frameworks is required to make them more accessible for researchers and practitioners. Through the review of the literature, it was highlighted that clearer structures, and systematic frameworks can allow researchers and practitioners to apply theories and readily inform their designs.

2.5.2 Origin and Structure of DiCoT

Distributed Cognition for Teamwork (DiCoT) framework first appeared by the necessity to develop a pathway on how to apply distributed cognition in a complex socio technical system (Blandford & Furniss, 2005). The researchers, drawing on the views and practical principles of Contextual Design (Beyer & Holtzblatt, 1997), developed a structured framework to conduct a DC analysis. DiCoT merges the structure in data collection and interpretation of Contextual Design with the theoretical basis of DC, to provide a useful modelling tool to investigate and understand human behaviour in a socio-technical environment. The "context" aspect in DiCoT highlights the need for in-

situ and field investigations. The authors borrow the five models included in contextual design and re-orient and enrich them with principles based on DC theory: (i) information flow model, (ii) physical model, (iii) artifact model, (iv) social model and (v) evolutionary model (Blandford & Furniss, 2005; Sharp et al., 2006). Each of these models is associated with principles from the distributed cognition literature, comprising a total of 22 principles fully desbribed in Furniss and Blandford (2006).

The three primary models of DiCoT that the majority of researchers focus are the physical, the information flow, and the artifact. The physical model of DiCoT relates to the physical organization of collaborative activities and covers all cases that are linked to physical layout (Blandford & Furniss, 2005). This model focuses on the aspects of the physical construction of the system and their impact on teamwork, such as the horizon of observation, and subtle bodily movements. Based on the aim and scope of the researchers, the focus can be differentiated, switching between the participants and primary locations of the system.

Focusing entirely on communication, the information flow model concentrates on the circulation of information omitting the design of the mediating artifact by which information is broadcasted (Blandford & Furniss, 2005). This model considers aspects of information movement, transformation, and hubs for decision-making processes. For the information flow model, the analysis depends on the depth of the analysis the researcher may need to examine; from concentrating the analysis on the general input and output information of the system, to directing the investigation towards the key players of the flow of information and identifying the channels of information and key examples.

The third dominant aspect of DiCoT framework is the artifact model, which examines the objects that contribute to the team working environment significantly (Blandford & Furniss, 2005). More specifically, the artifact model directs the analysis towards the role and design of artifacts central to the system, highlighting their affordances. For example, the model considers how the artifacts are used to scaffold activities within the collaborative working setting as well as the way the goal is represented by the mediating artifacts within the system.

Table 1: Summary of the five models underlying DiCoT

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 Structure	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.

Less expanded or optional models for the DiCoT framework are the social structures and evolutionary models (Blandford & Furniss, 2005; Furniss & Blandford, 2006; Sharp et al., 2006). More particularly, the social model includes two principles related to the social structural details of the team. The model concerns itself with the roles and responsibilities of the people in the system. It includes two principles related to goal structure and socially distributed properties of cognition associated with the social structure. The evolutionary model deals with the ways the systems has evolved over time, focusing on the evolution and differentiation of the system over time. It includes two principles related to cultural heritage and expertise coupling; that is considering system processes that allow an expert to perform activities faster. Table 1 summarizes the five models included in the DICoT methodological framework. Table 2 presents the DiCoT principles as classified in the five models mentioned above (Furniss & Blandford, 2006; Sharp et al., 2006).

Table 2: DiCoT principles per model

	No	Principle name and description
	1	Space & Cognition: Space as a way to support cognition during an activity.
	2	Perceptual: Spatial representations supporting cognition.
	3	Naturalness: Each representation match the features that it represents.
	4	Subtle Bodily Supports: How bodily actions are used to support activity.
	5	Situation Awareness: How are people kept informed of the activity.
	6	Horizon of Observation: What can be seen or heard by a person.
	7	Arrangement of Equipment: Physical arrangement affecting access to data.
	8	Information Movement: Mechanisms used to move information.
	9	Information Transformation: How information is transformed in the system.
	10	Information Hub: Central point of information flow and decisions.
	11	Buffering: Hold up information until it can be processed.
	12	Communication Bandwidth: Richness of information during communication.

	13	Informal and Formal Communication: Importance of informal communication channels.
	14	Behavioural Trigger Factors: Individuals act in response to certain behaviour.
	15	Mediating Artifacts: Elements used to fulfil an activity within the system.
	16	Creating Scaffolding: How people use environment to support their actions?
	17	Representation-Goal Parity: How close is the representation of current and goal state?
	18	Coordination of Resources: Plans, goals, history etc and their coordination to support cognition.
	19	Social Structure and Goal Structure: How the system evolves to distribute cognition within a group?
	20	Socially Distributed Properties of Cognition: How the social structure of the group impacts the goal structure of a group?
	21	Expert Coupling: What mechanisms an individual performs in the process of becoming an expert?
	22	Cultural Heritage: What elements of the collaborative workspace have changed over time?

The models and principles of DiCoT can help researchers from the organization of data collection procedures to guiding the analysis of the collected data. Analysis using the DiCoT framework involves capturing a rich data set in the field of the users and constructing detailed and descriptive accounts of the five different models of DiCoT. Such a descriptive analysis can help researchers understand the existing design of a system and reveal design insights for tools, processes, and the context (Blandford & Furniss, 2005; Furniss & Blandford, 2010). As the authors explained (Furniss & Blandford, 2010), DiCoT can bridge the gap from the descriptive analysis to the design of a new system. By drafting the basic mechanisms that exist within the cognitive system via DiCoT, a researcher can gain valuable insights and recognize "incremental design opportunities"; thus proposing how to re-design an existing system with clarity.

2.5.3 Empirical Work and Evolution of DiCoT

Since the initial investigation of DiCoT (Blandford & Furniss, 2005; Furniss & Blandford, 2006), the framework was evaluated and validated within a large ambulance call control centre (Furniss & Blandford, 2010). Furthermore, DiCoT has been also applied in various research studies under the project CHI + MED for evaluating and improving healthcare technology in collaborative working environments such as the intensive care unit (Furniss, Blandford, Rajkomar, Vincent, & Mayer, 2011; Rajkomar & Blandford, 2011; Rajkomar & Blandford, 2012a). Medical equipment in these contexts is considered of high complexity due to the strict and multiple interdependencies between nurses, doctors and healthcare technology. Researchers focused on exploring the design of different medical devices such as an infusion pump (Rajkomar & Blandford, 2012b), where even a small slip on the keypad can be lethal for the patient. For instance, McKnight and Doherty (2008) used the DiCoT as a methodology to analyse existing practices in cancer surgery unit, scaffolding their findings based on the five DiCoT models. The authors suggest that within such a high complexity setting, capturing every aspect is challenging, and DiCoT provides a promising technique. Similarly, Furniss Masci, Curzon, Mayer, and Blandford (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.

Researchers also applied the DiCoT framework in home-care investigations, focusing on the design of medical equipment. For example, Rajkomar, Mayer, and Blandford (2015) used the DiCoT framework to understand safety-critical interactions in a home haemodialysis technology. The researchers used DiCoT principle as the coding system for the analysis of collected data, aiming to unveil how this complex socio-technical system can support or hinder the safety of the patient. In another investigation, Rajkomar, Blandford, and Mayer (2014) focused their analysis of home healthcare on the temporal distribution of tasks and activities highlighting issues and opportunities in the design of home health technology and systems.

Stepping outside the healthcare system, DiCoT has also been valuable in understanding and expanding the collaboration and coordination paradigm amongst programming teams (Sharp & Robinson, 2008). Using DiCoT, Sharp et al. (2006) focused on understanding the value of different artifacts in an eXtreme Programming team. Such teams are highly collaborative and self-structured, breaking down the problem into single tasks. Through these numerous tasks, they manage to keep and distribute the status of each task, thus understanding the tools and coordination mechanisms they employ can contribute to the design of team-working tools and technologies. Targeting to improve a system on a particular layer of activities, Sharp, Giuffrida, and Melnik (2012) focused on the flow of information to map the interactions and coordination behaviour of a dispersed agile programming 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.

Researchers have also proposed some extensions of the DiCoT framework that they developed by revising DiCoT on a new setting or for a new analytical objective. For instance, Rajkomar (2010) observed and analysed an Intensive Care Unit (ICU) workspace and proposed the addition of two new models, the System Activity Model,

which can describe the complex operations of the system in an overview, and the Temporal Resources Model, to represent the sequential states of a task and the associated configurations. Both models were deemed essential in the context of the ICU system as they provide new angles of analysis to enrich the existing framework. Furthermore, Furniss et al. (2015) provided a more artifact oriented extension, namely DiCoT concentric layers (DiCoT-CL). The proposed framework introduces concentric layers as a means to provide an analytical understanding of the environment around a device at different levels, a promising technique for the design and use of medical or similar devices. Thus, providing context-based extensions of DiCoT can be a valuable contribution to the HCI community and reveal new aspects and new approaches that can be coupled with the existing DiCoT framework.

2.5.4 Strengths and Challenges of DiCoT

In this work, we focus on understanding classroom interactions during collaborative problem-based learning activities within an artifact ecology. Therefore, DC was considered an appropriate framework for building this understanding and highlighting affordances of the artifact ecology supporting collaboration and coordination. Our decision to use DiCoT was based on the fact that DiCoT combines the theoretical framework of DC and the structure that Contextual Design provides, in order to provide an effective modelling tool to investigate and understand human behaviour in a socio technical environment. However, the review of empirical work on DC and DiCoT revealed not only the strengths but also raised some concerns regarding the implementation of DiCoT in a classroom and learning environment. Thus, for the research design of this investigation we will take into consideration the inclusion of a pilot investigation to examine the feasibility of whether the collaborative learning activities can be mapped and explained using the DiCoT framework.

Another concern as indicated earlier, is that both social and evolutionary aspects of DiCoT are considered still underdeveloped and not as important as the three primary models. However, as seen in literature, social and cultural-historical aspects are deemed important and necessary for the understanding of complex, multi-tool and multi participant environments. Considering the limitations of DiCoT on these two aspects, we will consider the possibility of expanding using the current investigation.

Strengthening the DiCoT social and evolutionary models with new principles based on empirical data may allow the researchers to consider design implications that may impact the aspects of the system, which previously had been neglected.

2.6 Summary

This chapter presented a review of the main directions that research in artifact ecologies and shared spaces has been driven in recent years. The empirical work presented revealed the need for a detailed and rigorous analysis plan to understand and interpret complex socio-technical environments. This rich understanding can be obtained by studying a user or a group of users in its natural settings and propose design implications for the technology in need. Compared to theories presented in this chapter and summarized in Table 3, DC allowed researchers to highlight what is salient in the design of existing collaboration spaces and indicate aspects of redesign.

Table 3: Summary of contributions of theoretical perspectives in HCI

Theoretical Perspective	**Focus in HCI research**
Activity Theory	Focusing on the activity of the individual or group via the technology.
Situated Action	Focusing on the context or situation of the activity and how technology in our surroundings support the activity.
Ecological Psychology	Focusing on affordances or constraints of a tool that help users understand how to use it.
Distributed Cognition	Focusing on patterns of collaboration/coordination, breakdowns in existing practices and artifacts, to make suggestions for redesign.
Embodied Cognition	Focusing on the physical and social organization of surroundings.

However, as Rogers (2012) highlighted, even though practitioners appreciate the role of theoretical approaches such as distributed cognition, they do not perceive them as readily applicable. Through a review of analytical tools and structured frameworks, we also identified CD being adopted by practitioners to structure data collection and analysis. Combining the theoretical background of DC and the structural models of CD, DiCoT methodological framework was considered ideal. As demonstrated in this

chapter, DiCoT can help the researchers in the data collection and analysis of rich ethnographic data, and serve as methodological tool to understand collaborative activities in an artifact ecology.

Overall, up to date research has shown 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 aimed to understand the collaborative design activities within an artifact ecology in five different layers and extract design implications.

3 Research Design

This chapter reports on the employment of Multiphase Design (MD) as a mixed-method approach to understand the interactions evident in a classroom artifact ecology during group-work on a design task. To achieve this understanding, the study required a longitudinal and sequential investigation, breaking the overarching aim into working units that can be achievable across several phases. MD allowed us first to explore the artifact ecology in this new context, then evaluate the DiCoT framework in a novel context, followed by an in-depth investigation of the interactions to validate the DiCoT framework. This chapter defines MD and justifies its appropriation as an overarching approach for this dissertation, and articulate how MD frames this research investigation.

3.1 Mixed Method Research

Mixed-methods approaches have been widely exploited to study collaborative learning and cooperative work settings. For instance, Cross, Dickmann, Newman-Gonchar, and Fagan (2009) used a mixed-method design to explore and evaluate the level of collaboration between communities of well-being, health, and education. The authors assessed how the interactions between different stakeholders evolved over the duration of a project to provide a descriptive profile of their interactions, paying particular attention to networking data. Furthermore, various researchers used mixed-methods to study teamwork and collaboration in an educational setting, combining quantitative (i.e. questionnaire) and qualitative data (i.e. focus group) (Rossler & Kimble, 2016). To evaluate and understand complex human interactions that involve a social and cultural component, experienced researchers have blended both qualitative and quantitative data collection and analysis procedures. The rich data-set can allow the researcher to understand and interpret human behavior in a given context (Morgan & Shmircich, 1980).

Even more common is the use of mixed-method designs and their multi-facet understanding to describe and explain interactions in collaborative technological environments. For instance, Ke (2014) collected data on the collaborative activity of young students while participating in a design-based learning game. From observing students' activity and conversations, to surveying the sixty-four participants, the

researcher evaluated their mathematical thinking and learning uptake through the digital game and co-located collaboration. In another approach, a research group employed a mixed-method approach to comprehend the effectiveness of 3D virtual environments in collaborative learning processes (Bouta, Retalis, & Paraskeva, 2012). The researchers combined chat logs, field notes, as well as pre- and post- tests to understand behavioral, affective, and cognitive characteristics of the students' engagement in the virtual environment.

3.2 Multiphase Design

The Multiphase Design (MD) is an instance of a mixed methods approach to data collection and analysis, but with a far more complex research structure (Creswell & Clark, 2007). Mixed methods is a research approach, successful in social and behavioural sciences as well as in educational settings (Greene, Caracelli, & Graham, 1989), where researchers gather, analyse, combine, and explain both quantitative and qualitative data in a long-term project to address their research questions. Multiphase Design mixed-method research occurs when a researcher contemplates a problem through an "iteration of connected quantitative and qualitative studies" that are aligned sequentially or in parallel. Every iteration provides a new aspect of part of knowledge that when combined with previous iterations they address a specific objective (Creswell & Clark, 2007). The idea behind this research design is to combine a set of incremental studies that all contribute to an overall research objective. This research design can provide an ideal research paradigm to a multi-year project that requires multiple stages to address an overall research plan.

Researchers construct MD in such a way that it allows each individual study to build-up on the earlier findings and results. Each study or phase addresses a particular set of sub questions that will evolve into addressing the larger overall objective. MD is characterized as a sequence of approaches, qualitative, quantitative, or both, that build up to an overarching aim. MD usually has two or more sequential phases that produce a long-term or even multi-year examination that aims to provide a practical outcome. Both researchers and practitioners take part in data collection and analysis, contributing both their knowledge and practical experience. However each MD may follow a different structure or plan. In some cases, MD investigation may have a well-defined

plan with specific sub-research questions from the initial phase of the investigation. In other cases, when a research team employs a MD project, they may design and conduct the following steps based on the outcomes of the previous phases, and re-define research sub-questions as they emerge throughout the interconnected studies. These characteristics of MD research raise it as an ideal research paradigm for multi-year and practical oriented project. Nevertheless, this uniqueness builds up a strong profile for MD but also raises challenges that a researcher must consider during the design of the interconnected phases.

3.2.1 Appropriateness of Multiphase Design for this Dissertation

MD was employed in this dissertation as follows. The research work was conducted in four phases, including three sequential phases to collect and analyse data, and one integrative phase to incorporate data from previous phases and extract summative findings. To be precise, based on our aim to use an established framework, DiCoT, in a novel setting that was not previously explored, we identified the need to first explore the setting on its own and then examine the fittingness of DiCoT to validate it. This led us to a repetitive study design that allowed us to replicate the same setting in each of our phases without making significant changes to the context or environment. Next, this work focused on understanding, explaining, and interpreting the behaviour of students in such a context, using different participants as the investigation progresses from phase to phase. Using different participants from the same population for each phase served well as a way to evaluate the affordances of the artifact ecology and the individual artifacts of the ecology thoroughly. Last but not least, the overarching goal of this work was to provide a set of design implications that would guide the design of artifact ecologies for collaborative design activities. The practical orientation of this work therefore called for a MD research design, that as Creswell and Clark (2011) highlighted is one of the strengths of MD.

3.3 Research Methodology

In this work we focus on understanding and documenting learner-learner and learner artifact interactions in a classroom artifact ecology from a DC perspective. More specifically, this work had two overarching goals:

A. Propose design implications for researchers and practitioners for constructing efficient classroom artifact ecologies.

B. Transfer and assess DiCoT as a toolkit for understanding learner-learner and learner-artifact interactions in a classroom artifact ecology.

Considering the needs of this research study and the above mentioned strengths and challenges of the MD research approach, we structured a multiphase mixed-method design to address the research objectives of this work.

3.3.1 Research Questions

Overall, the MD required careful planning of the interconnected phases and the associated research questions as shown in Figure 8. We structured this dissertation in four phases in total, including three sequential phases to collect and analyse data, and one integration phase to incorporate and re-examine data from previous phases to extract practical implications. Based on the overarching goals of the study, a set of research questions was formulated, which were addressed in the four phases. More particularly, each phase includes two sub-research questions addressing each one of the two overarching aims of this dissertation.

- Phase 1 served as a pilot study for exploring the use of physical and digital tools in a Human Computer Interaction (HCI) course and the role of an artifact ecology in supporting collaboration and coordination around design tasks [RQ1.A]. Phase 1 also explored the appropriateness of a DiCoT analysis in this setting [RQ1.B].

- Phase 2 aimed to transfer and apply the DiCoT methodological framework into a classroom setting towards building an understanding of collaboration and coordination within a classroom artifact ecology. More particularly, the phase aimed to reveal the physical, communication, and artifact attributes of the artifact ecology based on DiCoT [RQ2.A] and to explore how DiCoT can explain the interactions between learners and artifacts [RQ2.B].

- Phase 3 focused on addressing the social and evolutionary aspects of the artifact ecology [RQ3.A] and proposing an expansion of the DiCoT framework [RQ3.B].

• Phase 4 aimed to integrate the findings from previous phases and provide design implications that emerge for constructing classroom artifact ecologies [RQ4.A], as well as to address how DiCoT can be used as a methodological toolkit to understand learner-learner and learner-artifact interactions in classroom artifact ecologies [RQ4.B].

Figure 8 presents a schematic representation of the research questions as they are spread across the four phases and two tracks of our investigation.

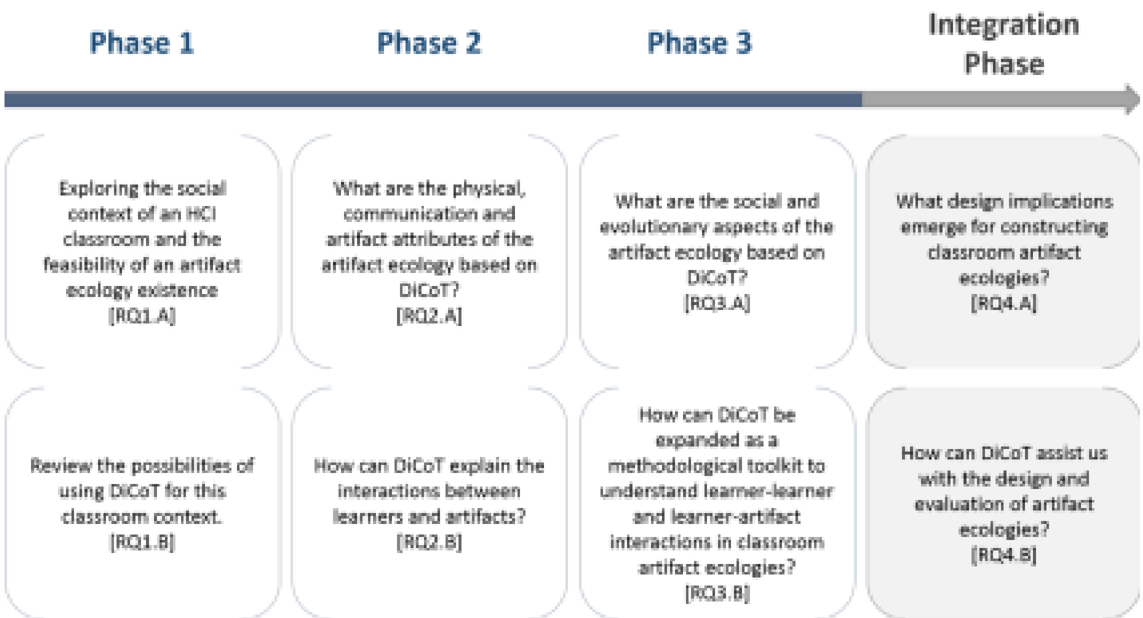

Figure 8: Research questions as divided across the four phases of this dissertation

3.3.2 Course Context

In this dissertation the three first phases include data collection that was conducted within three postgraduate HCI classes throughout 2012-2014 to capture a broad spectrum of the use of the artifact ecology across multiple groups (11 different groups). The courses were related to human-computer interaction, providing a practical and real world exemplar of user-centred design (UCD) process for the design of a product. The classes met face-to-face once weekly for 3 hours for 13 weeks and followed a problem based learning (PBL) structure.

3.3.2.1 Course Content: User-Centred Design

User-centred design is a term often used in HCI approaches to describe the process of involving end-uses in the design and development of a product (Vredenburg, Mao, Smith & Carey, 2002). It can be applied on many levels; on a lower level by using user based feedback to revise a product, on 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 set of techniques and methods to understand users and obtain valuable information to guide the design process (Karat, 1997).

As design activities, a UCD process involves five phases: analysis, design, evaluation, implementation and deployment. Within the context of this HCI course, students are required to pay 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, analysing 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, and storyboards, high and low fidelity prototypes of the product. The third phase and final step in the group work setting is the evaluation of the product through the combination of different evaluation methods, with the aim to revise the product before implementation. Methods often used are heuristics evaluation and usability testing for low or high fidelity prototypes, as well as cognitive walkthroughs and expert evaluations. Table 4 provides a weekly representation of the UCD phases and collaborative activities taking place in the classes.

Table 4: UCD phases and activities during the course (per week)

Phase/Activities	**Weeks**
Problem Introduction	1
Analysis	2-5
Design	6-9
Evaluation	10-12
Final Presentation	13

3.3.2.2 Course Pedagogy: Problem-Based Learning

The design process in the HCI course involved understanding and solving problems in an application context and shares similar stages with the PBL process, including problem analysis and brainstorming, assigning responsibilities for the investigation of information (learning issues), seeking and using knowledge, as well as critically evaluating the group's strategies and progress (reflection). Therefore, following a PBL approach in this course is relevant and desirable; doing so, provides students with an opportunity to not only participate in the PBL experience, but also to self-apply the very things they are learning about. A detailed description of the PBL process is found in Ioannou, Vasiliou, & Zaphiris (2016).

In particular, the course began by presenting students with a complex design problem with almost no information about how to solve it (Hmelo-Silver, 2004). Problems or tasks are of crucial importance to the success of PBL (Hung et al., 2008). The selected design tasks provided an open and real-world call for action, challenging learners to provide a viable and creative solution. The design tasks given to the groups for each phase of this dissertation were:

- Design Task for Phase 1: The problem given to students for the design project was derived from CHI2013 student design competition scenario, entitled "Empowering the Crowd: Changing Perspectives Through Collaboration". More particularly, learners were instructed to "design an object, interface, system or service intended to help us to develop and share awareness, understanding or appreciation for our collective and collaborative crowd experience as it relates to our changing perspectives through collaboration." (CHI Student Design Competition, 2013)
- Design Tasks for Phase 2: For the current in-class investigation the problem was derived from the student design competition of CHI 2007, entitled "Changing the Perspectives of Public Transport" (CHI Student Design Competition, 2007) and indicated the need to design an object, product or system that would promote the use of public transportation in Cyprus.
- Design Task for Phase 3: For the current in-class investigation the problem was

entitled “Changing the Public Behaviour around Health and Well-Being” and indicated the need to design an object, product or system that would enable a

change in the behavior of a selected group of people regarding their health and well-being.

The course was organized in 3-hour weekly sessions. Prior to attending each session, students had to study a textbook chapter. Each session began by presenting some information in a mini-lecture form of 20 minutes approximately to trigger attention on relevant issues students would have to consider during their problem-solving. This adaptation to the traditional PBL approach helps avoid possible gaps in students' knowledge, echoing Hmelo-Silver's (2004) thoughts that, “as students are grappling with a problem and confronted with the need for particular kinds of knowledge, a lecture at the right time may be beneficial” (p. 260).

The topics covered in the mini-lectures, naturally prompt learners to identify relevant learning issues. Learning issues were generated, researched, and taken up within the group's work during periods of 2-3 weeks, leading up to the design of the outcome group product for delivery at the end of the course. In general, the Koschmann and Stahl's (1998) phases of recognition (problem analysis, recognition of learning issues), researching (self-directed study of learning issues), reporting (group reconvene; newly acquired information is applied to the problem), and reflection (reflect on the information collected so far, clarify hypotheses and identify new learning issues) were evident during the resolution of learning issues. Table 5 presents two examples of learning issues and working through these phases (as presented in Ioannou, Vasiliou, & Zaphiris, 2016).

Following the mini-lectures, students worked in their PBL groups face-to-face, with the instructor and a tutor acting as facilitators. Comparing to the mini-lecture, the group activities aimed to enable student engagement and active collaboration within each group and were developed accordingly to the thematic unit of the associated mini lecture. Collaborative activities were usually two hours long and followed a PBL structure. More specifically, laboratories were consisted of three main units:

1. Weekly Reflection: A 20 minutes session to summarize and reflect on what has

been done since the last collaborative session (i.e. “What have we done since last week?”).

2. Brainstorming: Usually 80 minutes session, where students discussed about the progress of the project, readjust the problem based on the new facts and discuss

ideas for their following steps, associated with the recognition and researching phase. Finally,

Individual responsibilities division: A 20 minutes session to define what are the groups learning objectives and assigning responsibilities for individual research at home.

Table 5: Phases in the resolution of learning issues

	Learning issue 1	Learning issue 2
		decides if there is more to be learned from a human cognition perspective. New learning issues may emerge.
Recognition	The group decides they lack knowledge with regards to how cognitive psychology can inform the design of their system? The group assigns responsibilities for individual research at home.	The group decides they lack knowledge with regards to the needs of the prospective users of their system. The group decides on 8-10 questions to be answered during interviews and/or observation of prospective users.
Researching	At home, using print and electronic sources, individual learners engage in self-directed study of cognitive aspects of interaction (e.g., design of displays, information visualization, working memory capacity etc.)	Outside the classroom, individual learners conduct interviews and/or observations of prospective users to provide answers to the questions.
Reporting	The individual learners present their newly acquired information to the group. The group applies this knowledge and records ideas about the design of the system, from a human cognition perspective.	The individual learners present their raw data for the needs analysis meeting within their groups. All newly acquired information is applied to the problem.
Reflection	The group evaluates their current stage of knowledge, clarifies their thinking about the design of the system, and	The group evaluates their current stage of knowledge, clarifies their thinking about the design of the system, and decides if there is more to be learned regarding the

needs of the prospective users.

The role of the tutor during the collaborative sessions was to act as facilitator for students' self-directed learning. To manage all groups, the instructor and facilitator (individually) rotated from group to group and adjusted the time spent with each group according to the needs of the group (Hmelo-Silver & Simone, 2013). Particular attention was paid in guiding the reflection process, as suggested in Hmelo-Silver (2004; Hmelo Silver & Simone, 2013). Table 1 presents two examples of learning issues and working through these phases.

3.3.3 Artifact Ecology

We sought to create an artifact ecology, by enriching the classroom environment with various technologies aimed to support students' collaborative activities, particularly brainstorming, researching, reporting or reflecting, both in-class and in distance (in between the face-to-face sessions). Students were encouraged to use the technologies as they perceived appropriate for each activity and task. During the collaborative activities session, each group worked in a physical, technological set-up exhibiting three main attributes that we considered important for collaborative learning activity:

3.3.3.1 Shared Surface and Projection for Collaboration in Groups

The arrangement aimed to allow problem-solving and design conversations to take place around a large table surface. The same table surface was designed to be used as a projection surface for a downward-pointing projector (powered by a Mac mini and controlled by a wireless keyboard and mouse) as in Figure 9. The downward projection aimed to support the presentation of digital artifacts, such as images and notes captured in previous PBL sessions. This creative use of the projector was inspired by Jones, Fields, Bardill, and Williams (2010) who used downward-pointing projectors to support small groups of students on creative design projects at City University and Middlesex University, London. Moreover, students were provided with stationary (e.g., large-size paper, markers, post-it notes etc.) to take notes of their ideas as in traditional, low-tech

PBL settings. Also, three regular whiteboards (on rolling stand) were available in the classroom for groups to use as relevant.

Figure 9: Downward pointing projection

Figure 10: Mobile devices in the artifact ecology

3.3.3.2 Portable Devices for Mobility, Record-keeping, and Reflection

A tablet, an iPod, a sense cam, and a pen-reader were made available to each group during the collaborative sessions (see Figure 10). The purpose of the multiple portable devices was to provide a variety of tools, with different capabilities to support the diversity of tasks during collaborative activities. As highlighted in literature, these devices increase the mobility of participants (Everitt et al. 2006). Furthermore, these devices aimed to allow the capturing of key moments and artifacts during the activity to facilitate later review and reflection. For example, the iPod and tablet could be used to take pictures or record audio and video from the collaborative sessions; the sense cam

could automatically take pictures of the activity - one every 10 seconds; the pen-reader could turn personal paper notes and sketches into digital form to share with the group. Furthermore, learners were encouraged to enrich the artifact ecology with whatever portable devices they thought relevant, such as their own laptops, tablets, and smartphones.

3.3.3.3 Facebook Groups for Communication and Information Sharing

Each group was asked to set up and use a private Facebook group. Although this suggests a hybrid online and face-to-face environment, group collaboration, design conversations and problem-solving aimed to take place during the face-to-face collaborative sessions, rather than online. Instead, Facebook aimed to allow students to report the information they found during self-directed learning, between the face-to-face sessions. Furthermore, the Facebook group also aimed to support the coordination of any emerging issues in between meetings.

Tutors advised groups to appropriate the provided technologies for each activity and task, as well as enrich the artifact ecology with their own devices. Group members were also allowed to post material freely and manage the Facebook Group as owners of the group.

3.3.3.4 Artifact Ecology Design Decisions

Table 6: Artifacts within the artifact ecology in each phase

Phase	Artifacts comprising the artifact ecology
Phase 1	Shared Space: Downward-pointing projection Portable Devices: iPod, Tablet, Inkling Pen-reader, Sense Camera Communication and Information Sharing Platform: Facebook Group (closed and private)
Phase 2,3	Shared Space: Downward-pointing projection Portable Devices: iPod, Tablet, Inkling Pen-reader Communication and Information Sharing Platform: Facebook Group (closed and private)

Table 6 summarizes the artifacts within the ecology as used during the three phases of data collection within the HCI classes. The selection of artifacts to be included in the ecology was based on the necessity to provide a rich collection of heterogeneous tools that students would use them as they perceived appropriate during the collaborative design activities. The purpose of the multiple portable devices was to provide a variety of tools, with different capabilities to support the diversity of tasks during collaborative activities. However, tools that during Phase 1 study were revealed to be hindering collaborative design activities were removed from the ecology of artifact. For instance, the use of sense-camera was disruptive for the majority of learners as evident during the focus groups, and mobile devices could support better the mechanisms of capturing and reporting artifacts and moments for the progress of the project. Therefore, we considered removing the sense-camera from the set of digital and physical tools that compose the artifact ecology.

Another concern during the design of the artifact ecology focused on the use of Facebook for educational purposes. Researchers advocate over the use of Facebook as a tool for learning activities as it may increase collaboration, ease information and resource sharing, and facilitate interactions regarding a course (Mazman & Usluel, 2010). However, its use in a formal learning setting also raises some concerns. It is a social networking platform that was not designed for collaborative learning activities in a formal setting in higher education. In this sense, students and tutors mix their personal life in a learning and classroom environment and vice-versa that might create **Phase**

Artifacts comprising the artifact ecology

Phase 1	Shared Space: Downward-pointing projection Portable Devices: iPod, Tablet, Inkling Pen-reader, Sense Camera Communication and Information Sharing Platform: Facebook Group (closed and private)
Phase 2,3	Shared Space: Downward-pointing projection Portable Devices: iPod, Tablet, Inkling Pen-reader Communication and Information Sharing Platform: Facebook Group (closed and private)

disruptions while working (Wise et al., 2011) or even impact learning (Kirschner & Karpinski, 2010). However, the decision to move forward with the use of Facebook as a communication and coordination tool in each phase was also an aspect the students had to consider with the ability to object. In all three classes the students felt comfortable

using the tool as a communication and coordination for their classroom activities. Furthermore, we also used Phase 1 as a pilot and exploratory study to measure and assess the impact of Facebook on students' perceived learning.

3.3.4 Participants

We followed a purposeful sampling approach based solely on the criterion of individuals attending the targeted HCI course in the years 2012, 2013, and 2014 (Palinkas et al, 2015). In all cases, learners came from different postgraduate programs (MA in Interactive Multimedia, MA in Instructional Technology, and MSc in Games and Interactive Technologies), while their backgrounds varied (e.g., computer science, graphic arts, multimedia, education, communication, and internet studies). For the allocation of students in groups, we kept in mind the aim of creating multidisciplinary groups, as detailed in Table 7. Thus the procedure of forming groups was in part based on each student's background, including studies in computer science and games, graphic arts and interactive multimedia, and education and communication media. 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 had a member with expertise in graphic design that could help the group in creative design and 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 that could support the multifaceted needs of this project. Table 7 summarizes information on groups investigated in this work.

Therefore, each group was composed of members from different disciplines which can represent a valid sample of a possible work population. Even though the group members had different expertise and knowledge, the instructors of the course did not assign specific roles to the members of each group, but rather left them to emerge as the group felt appropriate. Group members had never worked together on previous projects and hence did not know each other's work practices. All students were familiar with digital technologies such as smartphones and tablets as well as with social networking spaces.

In terms of research ethics, an informed consent form was given to students at the beginning of the course to inform them about the measures taken to observe and record

their activities for the scope of this research (See APPENDIX I). The tutors and researchers made sure the learners comprehended all aspects of data collection procedures and the overall aim of this work. All participants from the three consecutive studies of this investigation agreed to voluntarily participate in this research study, ensuring that researchers would handle their personal data anonymously and with confidentiality, and that their participation or not would not affect the course mark.

Table 7: Summary and details of groups participating in this dissertation

Summary of Participants

Class 1 Number of Participants: 11 males and 19 females (N=30) – 5 groups

Age Span: 22-35 years old (M=29.8)

Groups' Expertise:

- Group 1 consisted of two computer scientists, two graphic designers, one with sociology background and one with special education experience.
- Group 2 consisted of two computer scientists, two graphic designers, and multimedia designers, two educators, and one member specialized in information management.
- Group 3 consisted of two computer scientists, two graphic

designers, and one member from education and learning science.

- Group 4 consisted of two computer scientists, two graphic designers, one member specialized in educational technology and one member from education and learning science.
- Group 5 consisted of one computer scientist, one graphic designer, one communications expert, one member with background in music therapy and special education, and two members from education and learning science.

Class 2 Number of Participants: 8 males and 13 female (N=21) – 4 groups

Age Span: 22-45 years old (M=30.1)

Groups' Expertise:

- Group 1 consisted of two computer scientist, two graphic designers, one member specialized in media and communications, one member with an education background.
- Group 2 consisted of one computer scientist, one game designer, one graphic designer and one member with sociology background.
- Group 3 consisted of two computer scientists, one graphic designer, two learning specialists, and one educator.