Designing Support for Collaboration around Physical Artefacts: Using Augmented Reality in Learning Environments

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Abstract

The aim of this thesis is to identify mechanisms for supporting collaboration around physical artefacts in co-located and remote settings. To explore the research question in the project, a Research through Design approach has been adopted. A technology probe — an evolutionary prototype of a remote collaboration system — will be used to fuel the research. The prototype will facilitate collaboration between small groups around physical artefacts in an augmented learning environment. The prototype will inform future collaborative augmented reality technology design.

Keywords: Collaboration, augmented reality, remote learning.

Index Terms: H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces—Computer-supported cooperative work; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 Introduction

Remote collaboration has become a part of everyday life for many people in recent times with the increasingly widespread availability of collaboration tools, including telephones, email, audio/video conferencing, shared repositories, and immersive environments. Ease of access to collaboration tools has allowed many organisations to operate across multiple sites and still collaborate across different physical locations. However as discussed by Olson and Olson in 2000 [1], *distance matters*; the distance over which people collaborate is important and will affect the collaboration. This is due to the different nature of collaboration mediated by tools compared to face-to-face co-located collaboration and the concessions required to make it work. Since 2000 technology has advanced and collaboration tools have improved resulting in some aspects of distance mattering decreasing [2].

With the advance of technology and continuing need for education and training, educational organisations have developed ways to provide distance education. Universities have started to use online learning management systems, such as *Blackboard* and *Moodle*, as both a companions to traditional physically taught courses and for courses taught entirely at a distance. Alongside universities, Massive Open Online Course (MOOC) platforms have developed. These platforms provide online courses that are taught to many thousands of students via the Internet only, generally with no certification for the students other than an optional Certificate of Achievement [3]. Online only delivery of education material allows for a wider distribution to the community however there are a number of drawbacks, in particular potential difficulties in collaborating with instructors and/or peers and lower student engagement and commitments, potentially leading to higher dropout rates.

The instruction and interaction methods for both online learning management systems and MOOCs are typically through recorded videos, lecture slides, discussion boards and similar web-based collaboration tools. These interaction methods provide basic collaboration for students however student engagement with others is low. Immersive environments create a collaborative environment which provides a more engaging experience for students [4]. Immersive environments are created using virtual and augmented realities. These altered realities create a shared space for students to collaborate in.

The research in this thesis explores the nature of remote collaboration around physical artefacts, where users can collaborate in a co-presence space for an educational purpose. To establish a clear problem space, existing physically co-located collaboration has been examined to determine the mechanisms and characteristics of a collaborative space to be provided remotely. The aim of this research is to identify the key mechanisms for supporting effective collaboration around physical artefacts in an augmented co-located environment.

2 Background

Remote collaboration applications have been developed extensively, however only a small portion of these applications deal with collaboration around physical artefacts or activities.

Fussell et al [5] looked at different pointing and representational gestures that have been used in a number of applications to allow users to indicate objects or tasks to other remote users. These gestures are complemented with conversation by the users using words such as '*this*' or '*that*' to refer to physical artefacts. The remote collaboration applications in which these are used typically are for video conferencing collaboration [5, 6]. These gestures while useful in these applications when moving to immersive environments are not as useful due to the different delivery method.

Along with gestures, Datcu et al [7] introduced physical artefacts into the collaborative workspace to aid in the collaboration. Physical artefacts can be manipulated as a control mechanism for supporting collaboration in conjunction with associated hand gestures. Alternatively hand gestures can be used to control digital representations of physical artefacts when remotely located [8, 9]. Many augmented reality collaboration applications [7, 8, 9] are able to provide ways of collaborating with physical artefacts, however they are mainly used as manipulation tools for the system or exist in purely digital form with no physical counterpart in another

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IEEE International Symposium on Mixed and Augmented Reality 2014
Science and Technology Proceedings
10 - 12 September 2014, Munich, Germany
978-1-4799-6184-9/13/$31.00 ©2014 IEEE

location. Datcu et al [8, 9] developed a collaborative augmented reality system that has participants construct digital towers out of digital blocks. Controlling the blocks is performed using hand gestures. These applications provide little sense of presence for remotely located participants as there is only an audio channel between them with no visual representation of remote participants.

There are multiple augmented reality systems that use avatars to represent remote participants in collaboration systems. Kantonen et al [10] developed a system that created avatars for remote participants using *Second Life* and *OpenSim virtual world*. Participants are able to view remote participants through head mounted displays and interact with digital objects. In the system developed by Maimone et al [11] 3D avatars are created on the fly using a Kinect device. Participants are able to interact with physical and digital artefacts, albeit with limited collaboration supported around them.

Church et al [12] found in co-located collaboration when working around a single artefact groups will often have a single leader and others will contribute less. By having multiple physical artefacts to contribute around, participants are more likely to contribute. Participants should be able to move freely around the space to access different artefacts and change their current task.

3 Research Questions

Observational studies of physical collaboration and survey of existing remote collaboration solutions will be used to develop an understanding of what mechanisms and considerations for supporting effective collaboration exist within the remote collaboration space. The mechanisms and considerations for supporting effective collaboration around physical artefacts that are identified will influence the design of a technology probe—an augmented reality collaborative system—to further investigate the mechanisms. Two final year university courses and a number of professional development courses for teachers will be observed to provide valuable real world insight into collaboration and a testing environment for the technology probe.

The overarching research question that will be answered during this thesis is: *When collaborating around physical artefacts in co-located collaboration, what mechanisms are important for effective collaboration, and how can they be supported in digital systems for remote collaboration?*

There are a number of research fields that inform this research, such as computer-supported cooperative work, collaborative learning environments, augmented/mixed realities, natural user interfaces, and distance learning. The research can be broken down into the following sub questions:

a. What mechanisms of physical co-located collaboration are important to effective group collaboration around physical artefacts?
b. Can these mechanisms be incorporated into a remote collaborative learning environment?
c. If these mechanisms can be incorporated, do they retain the same effectiveness? If they cannot be incorporated or lose effectiveness, what are the key differences between the two environments that cause the difference?
d. In augmented physically co-located collaboration, what mechanisms of remote collaborative learning environments are important for effective group collaboration?
e. Can these aspects be incorporated into the physically co-located space to improve collaboration?
f. What collaborative and augmented reality technology design guidelines can be identified for future collaborative augmented reality applications?

4 Methodologies

Research through Design (RtD) is a relatively recent research methodology that enables interaction design to contribute to Human-Computer Interaction research [13, 14]. Wicked problems, such as the research questions proposed in this thesis, are problems that are under-constrained and have no black-and-white solution [15]. Through the use of interaction design methods and an iterative design methodology, RtD allows researchers to find appropriate solutions to wicked problems. As such, this project uses the RtD methodology to answer the research questions. Interaction design methods used in the project include qualitative techniques such as observations, interviews, focus groups, and questionnaires [16, 17]. The quantitative technique of system analytics is also used. A research tool also employed is a technology probe [18], iterative designed and deployed, to assist in producing results.

4.1 Research through Design Process

Research through Design follows an iterative design and development process, with each iteration of the project is broken down into four different stages. The four stages are: *Identify needs/establish requirements*, *(Re)Design*, *Build an interactive version*, and *Evaluate* [16]. Each step in the process incorporates a number of interaction design methods.

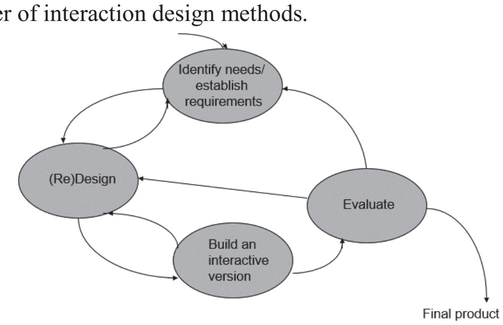

Figure 1: Interaction Design Model [16]

There are three major iterations in this project, which overlap with one another. Each iteration generates the input for the following iteration. The first consists of establishing an initial understanding of physical co-location collaboration and producing the technology probe, an augmented reality system to facilitate collaboration in the same location and remotely. The second iteration uses the probe in a studio course to evaluate its design and refine it for use in a professional development session. The third and final iteration evaluates the refined probe in professional development sessions.

4.1.1 Iteration 1

This iteration focused on understanding the problem space and explored the design of an initial technology probe, forming a first prototype of an augmented reality collaboration system. During this period, observation studies of both professional development courses and a university final year studio took place to provide an understanding of the existing state of collaboration around physical artefacts. The relevant literature of current implementation of collaborative learning environments was examined to establish the tools that are available and where improvements are possible.

Using the data gathered during this iteration, a technology probe—a prototype of a collaboration system—will be designed and developed to facilitate both local and remote collaboration. This prototype is influenced by a number of early throwaway prototypes. Evaluation of this prototype will consist of observational studies and interviews. This also constitutes the first stage of the second iteration.

4.1.2 Iteration 2

The second iteration overlaps with the end of the first iteration to evaluate remote collaboration using the technology probe. The probe is to be deployed in a university studio course and evaluated using an observation study, focus groups, interviews, questionnaires, and system analytics. The evaluation will be used to gather requirements for further refinements of the probe. The refinements to the probe will facilitate further insight into the mechanisms for collaboration around physical artefacts.

Using data gathered during the evaluation, rapid evolutionary prototypes of the technology probe are developed and deployed to the evaluation. Following the conclusion of the evaluation, a refined probe is designed and developed incorporating knowledge from the entirety of this and the previous iteration.

4.1.3 Iteration 3

The third and final iteration will commence with an evaluation of the refined probe in a number of professional development courses. The same evaluation methods from Iteration 2 will be used. Between each course refinements on the probe are developed and deployed to assist in the specific space of professional development courses.

The final evaluation of augmented reality collaboration around physical artefacts using the technology probe is used to draw conclusion in order to successful answer the research questions and provide the expected research contributions.

4.2 Technology Probe

The technology probe is an iteratively designed prototype augmented reality collaborative system that enables collaboration between local and remote users around physical artefacts. Throughout the project, the probe will have modifications implemented based on findings informed from data collected from its use.

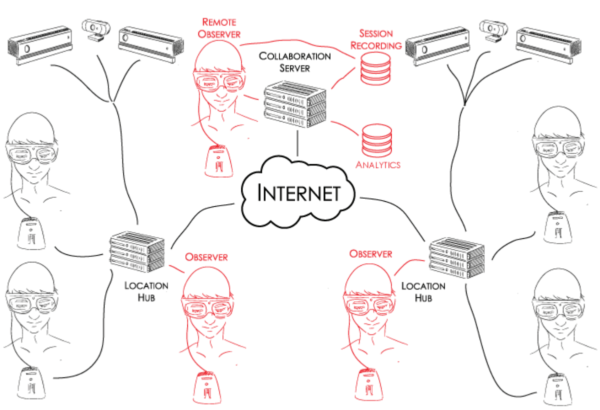

Figure 2: System Components of Technology Probe in use across Two Locations

The proposed system consists of a number of components: (i) one central server for managing collaboration between different locations, (ii) a number of different locations that are physically arranged similarly, (iii) one hub server at each collaboration location, (iv) two Kinect 2.0 connected to each hub server, (v) one high resolution webcam connected to each hub server, and (vi) one pair of optical see-through glasses with inbuilt microphone, speakers and depth camera with a pocket computer for each participant. The different components of the system are shown in Figure 2 for collaboration between four people at two different locations. The figure also shows the observational parts of the technical probe in red. The central collaboration server will store recordings of each collaboration session that can be replayed by an observer at a later time. The central server also analyses the collaboration in each session. Analytics to be used include turn taking in conversation between same location and across multiple locations, and length and type of interaction with physical artefacts.

To facilitate collaboration between multiple locations the system creates a shared collaborative learning environment in augmented space. The environment encompasses people, the physical artefacts in the collaboration space, and digital artefacts. This allows interaction between users in a common, shared space that revolves around artefacts both physical and digital.

The system treats each physical location as a primary site for collaboration, giving each user an egocentric view of the augmented space. Remote participants are viewed as avatars by other users. High resolution avatars of all participants are recorded before the collaboration commences, and are transmitted to all locations. High resolution 3D avatars of each of the participants will result in greater realism being present for remote participants. Figure 3 shows the system in use with four participants in total, two who are physically present and two as avatars who are remotely located. Physical artefacts are virtualised during collaboration and transmitted to remote locations. The two Kinects' placed opposite one another allows participants to move around the augmented space and continue being tracked by the system.

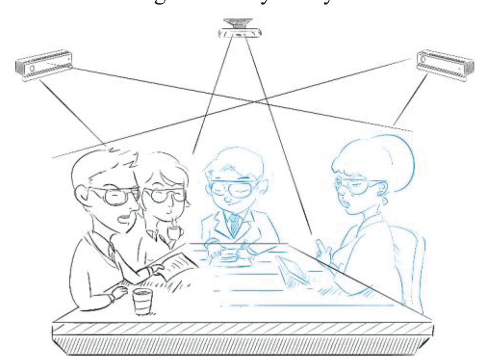

Figure 3: System in use by Four Participants, Two Local and Two Remote

The system does not enforce any roles on participants but allows them to determine roles themselves through social constructs. Participants in the same physical location as physical artefacts have privileged control of them due to their physical co-location; remote participants can interact with them through control suggestions that can be acted on by local participants.

5 Results to Date

Three observational studies have been completed. The first two studies observed professional development courses for teachers while the last observed a final year university studio course. From the observational studies a number of behaviours of participants have been identified and will influence the design of the initial prototype.

a. Participants observed the instructor when they presented material. Participants stopped working and focused on the instructor, potentially taking notes or photos.
b. Participants faced other participants and focused on the speaker/active participant.
c. Normally an active participant was in control and others provided instructions. Roles within the groups were informal and swapped casually between participants.
d. Participants at times stopped working together and worked individually towards a join goal.
e. Participants swapped their focus from what they were doing to other tasks, such as stopping to look for help, back and forth to achieve their current goal.
f. Participants in short courses formed into fluid groups for the course. The groups combined and split multiple times.
g. Participants in long courses formed into fixed groups for the duration of the course.
h. Participants collaborated around mobile physical artefacts (paper, tablets) by passing them between one another.
i. Participants collaborated around fixed physical artefacts (physical constructions, computers) by moving around the artefact to see it.
j. Group participants that did not work together in the same location disputed the work each contributed.

Based on the findings from the observational studies a number of implications for the design of the technology probe are presented here. The findings reinforce some of the design decisions of the initial probe and suggest further modifications. The findings include:

a. Artefacts should be able to added to, updated, and removed from the collaboration fluidly.
b. Groups should able to be created dynamically through social constructs.
c. Roles within the group should be dynamic and set through social constructs.
d. Each users should be able to see every other user participating in the collaboration. They should be aware of their presence.

6 Expected Contributions

This thesis will make a research contribution by identifying key mechanisms for facilitating effective collaboration around physical artefacts in augmented collaborative space. Along with identifying the mechanisms, the process of designing the prototype and the prototype itself will inform future technology design and contribute to research in the fields of Research through Design, and Collaboration in Mixed and Augmented Reality.

7 Current Situation

The technical probe—the augmented reality collaboration system—to be used during this thesis is under active development. Testing of the probe will be critical to ensure that after deployment there are no implementation issues that will detract from the experience of the participants.

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