Developing and evaluating a technology enhanced interaction framework and method that can enhance the accessibility of mobile learning

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Abstract. This paper focuses on the development and evaluation of a Technology Enhanced Interaction Framework and Method that can help with designing accessible mobile learning interactions involving disabled people. This new framework and method were developed to help design technological support for communication and interactions between people, technology, and objects particularly when disabled people are involved. A review of existing interaction frameworks showed that none of them helped technology designers to consider all of the possible interactions that occur at the same time and in the same place (i.e. face to face situations). Since almost all learners and teachers now have access to mobile technologies the new framework and method provide great potential for learning through interactions in these face to face situations. The components of the framework are described and explained, and examples of interactions are provided. The Technology Enhanced Interaction Framework has been developed and validated using technology designers and accessibility experts. To help designers apply the framework, the method has been developed and validated using technology designers and accessibility experts, and was successfully evaluated with technology designers.

Keywords: Mobile Web, interaction framework, disability

Introduction

This paper focuses on the development and evaluation of a Technology Enhanced Interaction Framework and Method that can help with designing accessible mobile learning interactions involving disabled people. The framework has been developed as a support for software designers in their consultations with domain experts (e.g. teachers and students) and disabled people. Mobile devices have become pervasive in education with a recent survey by a UK University showing 99% of students had a laptop and 91% also had a mobile phone with internet connection and 36% also had a tablet (Grussendorf, 2013). However the World Wide Web Consortium Web Accessibility initiative has not yet developed guidelines for mobile accessibility and states “There are not separate guidelines for mobile accessibility. … We plan to provide more guidance on applying WCAG and UAAG in the mobile context” (Henry, 2013). As information and communication technology has become more important in society, many researchers have been concerned with how to use technology to support communication between people and improve interactions between people, technology and objects (Berne, 1964; Dix, 1995; 1997; Dix et al., 2004; Laurillard, 1993; Rukzio, 2008; Sung et al., 2010; Vyas, Dix, & Nijholt, 2008). There has, however, been no framework that has helped technology designers or developers to consider all of the possible interactions that occur at the same time and in the same place. Since almost all learners and teachers now have access to mobile technologies the new framework and method provide great potential for learning through interactions in these face to face situations. There have been projects concerned with how to use technology to support some interactions. For example, artefact-mediated-communication has been used to support cooperative work (Dix, 1997; Dix et al., 2004; Hsi & Fait, 2005; Larson, Raman & Raggett, 2003), a mobile digital guidebook has been used to enhance visitors' interaction with physical objects in museums (Dix, 1994; Lee et al., 2009) and mobile devices have been used as mediators for the interaction with a physical object using Quick Response (QR) codes, Radio Frequency Identification (RFID) tags and Near Field Communication (NFC) tags (Broll et al., 2007; Rukzio, 2008). Many publications and projects in human computer interaction (HCI) focus on using technologies as a tool to enhance experiences: in the same place but at a different time (e.g. using systems for supporting group learning such as notice boards, questions and answers, electronic debates and collaborative learning (Lee et al., 2009); in a different place but at the same time (e.g. using a Synchronous Communication Tool such as video conferencing, instant messaging and online chats to interact with learners to improve their communication with the Instructor (Wang, 2008); and in a different place at a different time (e.g. using blended learning, students can access e-learning in order to learn in a different place at a different time (Klink, 2006). The general interaction framework described in this paper has been adapted from and extends the work of Dix (1994) and Gaines (1988) to help design technology to support communication between people and improve interactions between people, technology and objects, particularly in complex situations.

The paper is structured as follows: presentation of research questions, reviewing previous research on interaction frameworks including mobile learning, explaining the Technology Enhanced Interaction Framework (TEIF), explaining the TEIF Method, presenting a mobile web solution for a learning scenario, expert validation and review findings, experimental pilot studies, experimental design and participants, questionnaire results and analyses, discussion, and conclusion with a mention of the future work taking place to enable the Framework and Method help designers design technology to enhance face-to-face interaction in the same time and the same place using mobile applications.

Research questions

The following research questions and sub questions were identified and explored through this research:

Research question 1: Can a Technology Enhanced Interaction Framework (TEIF) be developed regarding disabled people interacting with people, technologies and objects? It was answered through an expert validation and review of the TEIF by three designer experts, three accessibility experts and one HCI professor.

Research question 2: Can a TEIF Method be developed building on this TEIF to help design technology solutions for disabled people interacting with people, technologies and objects? It was answered through an expert validation and review of the TEIF Method by three designer experts, three accessibility experts and one HCI professor.

Research question 3: Can designers use the TEIF Method to help with the software development process when designing technology solutions to interactions for disabled people with people, technologies and objects?

To help answer this research question, four aspects of the software development process were explored through the following sub research questions:

Sub research question 3.1 focussed on evaluating requirements; can designers use the TEIF Method to help with evaluating requirements when designing technology solutions to interactions for disabled people with people, technologies and objects? This sub research question was answered through experiment and questionnaire.

Sub research question 3.2 focussed on evaluating technology solutions; can designers use the TEIF Method to help with evaluating technology solutions when designing technology solutions to interactions for disabled people with people, technologies and objects? This sub research question was answered through experiment and questionnaire.

Sub research question 3.3 focussed on gathering requirements; can designers use the TEIF Method to help with gathering requirements when designing technology solutions to interactions for disabled people with people, technologies and objects? This sub research question was answered through a questionnaire.

Sub research question 3.4 focussed on designing technology solutions; can designers use the TEIF Method to help with designing technology solutions to interactions for disabled people with people, technologies and objects? This sub research question was answered through a questionnaire.

Research question 4: In what ways does the TEIF Method help designers/developers?

To help answer this research question the following sub research questions were explored through questionnaire responses.

Sub research question 4.1: Does the TEIF Method helped to improve awareness of interaction issues involving hearing impaired people?

Sub research question 4.2: Does the TEIF Method help to improve their understanding of how environment context affects interaction when hearing impaired people are involved?

Sub research question 4.3: Would the technology suggestions table in the TEIF Method be helpful for designing technology solutions to interaction problems involving hearing impaired people?

Sub research question 4.4: Is using the whole TEIF Method more helpful for designing technology solutions to interaction problems involving hearing impaired people than just using the technology suggestions table part of the method?

Review of interaction frameworks

A review of interaction frameworks showed none of the frameworks have assisted technology designers and developers to consider all of the possible interactions that occur at the same time and in the same place although there have been projects concerned with how to use technology to support some of these interactions. Table 1 summarises a review of interaction frameworks and shows that seven frameworks focus on direct communication in the same time and at the same place (Abowd & Beale, 1991; Berne, 1964; Dix, 1994; Foulger, 2004; Klink, 2006; Laurillard, 1993; Sacks, 1974), ten frameworks mention interaction between people and technology (Abowd & Beale, 1991; Cook & Hussey, 1995; Dix, 1994; Flanders, 1960; Jetter et al., 2012; Klink, 2006; Larson et al., 2003; Lee et al., 2009; Norman & Draper, 1986; Rukzio, 2008; Sung et al., 2010), eight frameworks focus on using technology to mediate interaction between people (Dix, 1994; Ellis, Ridolfi & Zwirner, 1991; Jetter et al., 2012; Klink, 2006; Lee et al., 2009; Rukzio, 2008; Sung et al., 2010; Vyas et al., 2008), and two frameworks consider using technology to enhance interaction between people and objects (Jetter et al., 2012; Sung et al., 2010). However, only the Human Activity Assistive Technology Model (HAAT) (Cook & Hussey, 1995) considers accessibility in the interaction. The communication between people is a complex subject (Dix, 1994). Bern (1964) identified roles of parent, adult, and child in his theory of Transactional Analysis. The conversational framework developed by Laurillard (1993) describes how the roles of teachers and students interact in the learning and teaching process. For example, in a school classroom; the teacher's role is characteristically to provide information, show examples, ask questions, and provide feedback. A student characteristically undertakes learning activities such as listening, asking and answering questions. People have abilities or disabilities which can affect their use of technology or understanding of language and which can lead to communication breakdown. For example, students may be deaf or blind, have difficulty in learning or using technology, or be international students with difficulties in understanding a non-native language of instruction. The ability or disability can also affect interaction breakdown, e.g. people may refer to particular objects and technology by pointing; this is known as deixis (Dix, 1994) which a blind student would not see.

There are some other frameworks that have some relevance to mobile learning. Sung et al. (2010) proposed a framework for designing a mobile electronic guidebook for a history museum. An electronic guidebook was implemented and evaluated in comparison to a worksheet and visiting without any guidebook or worksheet. Users spent the most time with exhibits when using the electronic guidebook but there were no significant differences in the knowledge gained about exhibits. Their framework did not consider a scenario where an expert presented or explained the exhibits. Rukzio (2008) presented a physical mobile interaction framework for using mobile devices as mediator for the interaction with a physical object and discussed purpose, need, training, information overload, item headings, initial items, and activity. Klink (2006) evaluated the use of synchronous and asynchronous interaction its implementation in outdoor museums.

Lee et al. (2009) focused on the use of asynchronous computer mediated communication (CMC) systems for supporting group learning and identified as critical success factors educational methods in the blended learning environment and concluded that more attention should be paid to online students and that there is needed to be more variety in interaction methods. Critical success factors identified were lecturers' time, effort and cost of high quality resources (e.g. interactive animations). Gaines (1988) presented a conceptual framework for person-computer interaction in complex systems based on an analysis of systems theory literature to derive design principles for person-computer interaction and a hierarchical model of person-computer systems. His model acknowledges a technological system's behaviour reflects the value systems and inter-personal attitudes of the system designer and so the same systems principles apply to the psychology, sociology, human-computer interaction, and computer-computer interaction. Norman's model of interaction (Norman & Draper, 1986) is a useful means of understanding the interaction between human user and computer. It allows other works to extend the common model. However, the model only considers the system as the interface; it doesn't deal with the system's communication. Norman uses this model of interaction to illustrate why some interfaces cause problems to users. This is because the user and the system do not use the same terms to describe the domain and goals. Abowd and Beale (1991) extended Norman's model to include the input and output components of the user interface.

There is a framework that addressed the issue about accessibility (Cook & Hussey, 1995) which modified Bailey's Human Performance Model in order to accommodate assistive technology. The components of their model are: human (abilities/skills), activity (determined by role), context (setting, social, cultural, physical), and assistive technology (hardware, software, non-electronic). The extensive guidelines for accessibility and usability (Petrie & Bevan, 2009) (e.g. WCAG 2.0, BS8878, Neilsen's usability heuristics, Shneiderman's 8 golden rules, etc., W3C MWBP, etc.) refer only to the interactions between people and technologies and not the other types of interactions identified in Table 1. However, no other current framework addresses all of the interactions identified in Table 1. The TEIF addresses this, as explained in the next section. The concepts of accessibility, usability and user experience highlight a current lack of agreement about whether accessibility means universal design or usability for older and disabled people. The role of accessibility, usability and user experience evaluations in the design process was also considered. Universal design can benefit disabled people by increasing their culture, citizenship, democracy, and equality in accessing information. To design for all may not always be possible for all disabilities, designing based on the users' requirements may be sometimes be necessary. However, society cannot ignore the potential offered for people with disabilities even though companies may have to pay more in order to design for all because of the legislation. Most of the software engineering approaches have not considered disabled people or complex situations. This can result in lack of consideration of the needs of disabled people during the software engineering process.

The Technology Enhanced Interaction Framework

The Technology Enhanced Interaction Framework (TEIF) focuses on the development of a general interaction framework to help design technology to support communication between people and improve interactions between people, technology and objects, particularly in complex situations involving disabled people. The TEIF also addresses the issue that, until now, no existing interaction framework was designed to help technology designers to consider all of the possible interactions that occur at the same time and in the same place. The TEIF can be applied to different environments and contexts and in this paper it is centred on mobile learning environments.

Terminology

- Communication is the process of passing information from one person to another (Merrill, 2008).
- Technology is a tool that helps people achieve their purpose. People means anyone involved in direct communication or interaction with an object, technology, or people.
- Object is anything that is not a technology or a person involved in communication or interaction.
- Interactions can be between people and objects (P-O) or people and technology (P-T). People can also use technology to mediate interaction with people (P-T-P) or objects (P-T-O).

Main Components

There are seven main components in the TEIF. A person has a role when communicating with others (e.g. presenter, audience, peer). Roles normally come in pairs such as speaker and audience (e.g. teacher and student or owner and visitor) and peer to peer (e.g. student and student or visitor and visitor). People have abilities and disabilities which can affect their use of technology or understanding of language and which can lead to communication breakdown (e.g. physical, sensory, language, culture, communication, Information Technology (IT)). The components "Object" and "Technology" are used in order to extend Dix's framework to show any type of interaction. Objects are defined as having three sub-components: dimensions, properties, and content. Technology has a cost and can be electronic or non-electronic, online or off-line, and mobile or non-mobile.

Table 1. Summarising a review of frameworks of interactions

	Transactional analysis	Conversational Framework	Conversation Analysis	Interaction Analysis	Role of Artefacts in Mediated Communication	Computer supported cooperative work - A framework	The Physical Mobile Interaction Framework (PMIF)	Designing an electronic guild book for learning engagement in a museum of history	Multimodal Interaction Framework W3C 2003	Norman's model of Interaction	The Interaction Model	A Ecological Model of the Communication Process	a time/space matrix to classify synchronous and asynchronous technology	Human Activity Assistive Technology Model	Systems for supporting group learning	A Conceptual Framework for Person-Computer Interaction in Distributed Systems	Blended Interaction	Blended Learning	Technology Enhanced Interaction Framework
Direct Communication																			
People-People (P-P)	✓	✓	✓	✓		✓						✓						✓	✓
Interactions																			
People-Technology (P-T)							✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
People-Object (P-O)																			✓
People-technology-people (P-T-P)					✓	✓	✓	✓					✓		✓		✓	✓	✓
People-technology-object (P-T-O)								✓									✓		✓
Role of interaction																			
Presenter-Audience																			✓
Sender-Receiver														✓		✓	✓		✓
Teacher-Student		✓		✓															✓
Consumer-creator												✓							✓
Speaker-Audience								✓					✓						✓
User-system					✓				✓	✓	✓			✓	✓	✓	✓	✓	✓
Peer-peer						✓	✓								✓				✓
No role	✓		✓				✓												✓
Space/Time																			
Same place/same time	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓
Same place/ different time									✓				✓		✓			✓	✓
Same time/ different place									✓				✓					✓	✓
Different time/ different place									✓				✓					✓	✓
Technology enhancement																			
Using technologies					✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓
Without technology	✓	✓	✓	✓								✓							✓
Accessibility																			
Consider accessibility														✓					✓

Furthermore, it may or may not have stored content and may additionally have an interface and be an application or provide a service. Interactions and communication are classified into three groups:

Direct communication: P-P - people in one way or two way communication with people.

Direct Interaction: P-T - people can control technology and may also use it to store or retrieve information; P-O - People can control objects and retrieve information from objects.

Technology Mediated Interaction: P-T-P - technology can mediate communication between people (e.g. people using their smart phones to communicate to each other by sending SMS or MMS messages, calling, sending email, sharing information through Bluetooth, or text chatting through mobile applications.); P-T-O - people can control objects with technology and may also be enabled to use objects to store and retrieve information (e.g. people controlling their mobile phones to take photos of a building or scan QR codes on the building).

Time and Place can be divided into four categories (Ellis et al., 1991): same time and same place, different time but same place, same time but different place, and different place and different time. Context can include factors and constraints such as location, signal quality, background noise, and weather conditions. The role played by the interactions and communication may be classified into one of six interaction layers, adapted from Gaines (Gaines, 1988) as shown by the example of pressing of the letter 'h' on the keyboard when typing "hello" as a greeting when sending a text message:

- Cultural layer includes countries, tradition, language, and gesture (e.g. hello is greeting used in the culture).
- Intentionality layer involves understanding, purpose, and benefit (e.g. greeting).
- Knowledge layer involves facts, concepts, and principle (Gaines, 1988) (e.g. how to spell the word "hello").
- Action layer involves actions and procedures (Merrill, 2008) (e.g. pressing key 'h').
- Expression layer describes how actions are carried out (e.g. pressing the correct key).
- Physical layer is the lowest layer at which people interact with the physical world (e.g. button is depressed sending letter code to the application).

Architecture of the Technology Enhanced Interaction Framework

The overall architecture of the TEIF involves people, technology, and objects (Figure 1). The general framework covers the use of any technology, which may or may not be electronic; the main difference is that electronic technology can store and manipulate information.

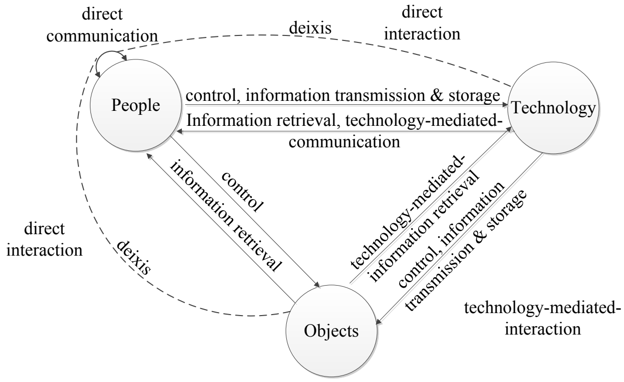

Figure 1. The Technology Enhanced Interaction Framework extended from Dix

The Technology Interaction Framework Method

The TEIF Method has been developed based on the TEIF, to help a designer who is not an accessibility expert to understand the problems and solutions faced by disabled people so that the designer can ensure that their designs are suitable for all users. The TEIF Method consists of 19 multiple choice questions to elicit requirements based on the components of the TEIF. Designers analyse their scenario and answer the questions. The answers will suggest relevant technologies. The technology designer decides on the solution based on the technology suggestions and discussions with their client. The example of how to design a possible technology solution is shown in the technology solution scenario (Table 2) and interaction diagram (Figure 2). In order to explain how the framework is instantiated in the TEIF Method, the following example accessible mobile learning scenario is provided which suggests requirements for a technology solution.

Suchat Trapsin allocated some parts of his house to become the Museum of Folk Art and Shadow Puppets, in Thailand. There are exhibits of shadow puppets inside the museum, but there is no information provided in text format. This is because Suchat normally explains the history and tradition in Thai by talking to visitors. He presents the same information in the same order every time. On Friday afternoon, a group of University students including Chuty (who has been hearing impaired since birth) and their lecturer visit the museum as part of their tourism module to learn more about it. Suchat starts the talk by explaining about the exhibits. During the talk, Chuty finds that it is very difficult to hear Suchat clearly. Chuty asks Suchat some questions about the exhibits. Suchat answers the questions, but Chuty misses some of the words. While Chuty is watching the shadow puppet show, she also cannot hear the conversation clearly because of the background music which is part of the show. It is also fairly dark which makes lip-reading very difficult for them. Suchat would like to have a technology solution that makes it easier for Chuty to understand him. There is good Wi-Fi at the museum so he would like to use Chuty's smartphone to keep his costs low.

Requirement questions, answers, and explanations

1. What is the main purpose of technology solution? Answer: a. improve communication, Explanation: Suchat would like to have a technology solution that makes it easier for Chuty and her parents to understand him.
2. Where and when does the scenario take place? Answer: a. same time / same place, Explanation: Suchat and Chuty are in at the Museum of Folk Art and Shadow Puppets, Thailand on Friday afternoon.
3. What main role do people have in the scenario? Answer: a. presenter – audience, Explanation: The "presenter" (Suchat) talks to the "audience" (Chuty) and the audience ask the presenter questions.
4. How many presenter and audience members are there? Answer: a. one presenter – many audience members, Explanation: Suchat is a person who gives the information to Chuty.
5. Does the presenter have a disability? Answer: b. No, Explanation: Suchat doesn't have any disability.
6. What language does the presenter use? Answer: b. Thai, Explanation: Suchat talks to Chuty in Thai.
7. What language does the audience use? Answer: b. Thai, Explanation: Chuty is a local person who lives in Thailand.

8. Does the audience have a disability? Answer: a. Yes, Explanation: Chuty has a hearing impairment.
9. What kind of disability does the audience have? Answer: a. hearing impaired, Explanation: Chuty has had hearing impairment at birth.
10. What level of hearing loss does the audience have? Answer: c. I don't know, Explanation: there is no detailed information about the level of hearing loss of audience member in the scenario.
11. What two interaction types occur in the scenario? Answer: a. P-P and b. P-O, Explanation: Suchat communicates with Chuty (P-P) and Chuty watches the shadow puppet show (P-O).
12. What type of technology would be appropriate for the solution to the scenario? Answer: a. online, Explanation: there is good Wi-Fi at the museum and Suchat would like to use Chuty's smartphone.
13. What type of technology devices would be appropriate for the solution to the scenario? Answer: a. mobile devices, Explanation: Suchat would like to use Chuty's smartphone.
14. Has the presenter planned what he wants to say? Answer: a. Yes, Explanation: Suchat has already prepared what to talk to the visitors about.
15. Are audio or video recordings shown in the scenario? Answer: c. neither, Explanation: there are no audio or video recordings shown in the scenario. The music is just a background sound.
16. Where does the situation take place? Answer: a. indoors, Explanation: inside the museum (the Museum of Folk Art and Shadow Puppets).
17. What are the main environmental considerations identified that impact the scenario? Answer: a. noise and e. lighting, Explanation: Chuty cannot hear the conversation clearly because of the music background which is part of the show. It is also fairly dark which makes lip-reading very difficult.
18. Does the customer have a limitation of cost in designing technology? Answer: a. Yes, Explanation: Suchat would like to use audience's smartphones to keep his costs low.
19. Should the technology solution work on a smart phone? Answer: a. Yes, Explanation: Suchat would like to have a technology solution that makes it easier for Chuty to understand him using their smartphone.

Technology Suggestions Table

The key requirements answers from the gathering requirement stage link to the technology suggestions tables (Table 2) which indicate possible technology suggestions. Table 2 shows 10 technology suggestions from the 22 available. Note that the column furthest to the right (Total score) shows the number of scenario requirements met by each technology suggestion. Ticks (indicating the requirement is met by suggested technology) and crosses (indicating the requirement is not met by the suggested technology) are shown in Table 2. One of highest scoring technologies is the mobile web site which addresses all of the problems and requirements but the decision about technologies to implement would depend on their cost and prioritization of the relative importance of requirements. To help designers and developers understand how to follow the suggestions, an example mobile web solution is provided which also includes other suggested technologies in designing the solution.

Table 2. Technology Suggestions

Technology suggestions	Which scenario requirements the technology meets																
	1a.improve communication	2a.same time/ same place	3a.presenter-audience	6b. speaker speaks Thai	7b. presenter speaks Thai	9a. hearing impaired	11a. people – people	11b. people - objects	12a.online technology	13a.mobile devices	14a.pre-prepared speech	16a. indoor	17a. noise	17e.inadequate lighting	18a. low cost solution	19a. work with phones	Total Score
Mobile web site	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Pre-prepared caption	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
FAQ	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
QR-codes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Instant messaging	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	15
Short Message Service	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	15
Vibrating alert	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	15
Speech recognition	✓	✓	✓	×	×	✓	✓	×	✓	✓	✓	✓	×	✓	✓	✓	12
Internet Protocol Relay	✓	✓	✓	×	×	✓	✓	×	✓	✓	✓	✓	×	✓	×	✓	11
Voice Carry Over	✓	×	✓	×	×	✓	✓	×	✓	✓	✓	✓	✓	✓	×	×	10

Mobile Web Solution for Scenario

The mobile web solution scenario presented in Figure 2 is a part of the example of how the technology suggestion tables can help in the design of technology solutions. From the mobile web solution, Suchat has a role in the communication which is important because he can control technology to send an instant message to Chuty's phone to make it vibrate to let Chuty know when the conversation starts. The technology solution selected to enable this is instant messaging which was chosen over SMS because it is free using wireless and smartphones (Harper & Clark, 2002; Isaacs et al., 2002; Sheng & Xu, 2010). Moreover, it can also vibrate Chuty's Smartphone which is better than turning lights in the room on and off to notify her as this may not be noticeable in sunlight. Captions can be of value to everybody, especially people with no useful hearing, and were selected as the solution of choice (Bain et al., 2005; Dror & Harnad, 2008; Cambra, 2009; Suebvisai et al., 2005; Wald, 2002). Thai speech recognition is not very accurate for spontaneous speech (Dror & Harnad, 2008) and therefore as Suchat already knows what he plans to say the best solution is pre-prepared summary captions. As he presents his talk Suchat controls the changing pre-prepared captions on the mobile website using his smartphone. He has an application on his phone that can send a message to the webserver to display the next caption on the webpage that Chuty is looking at. This solution was chosen over using a pre-prepared captioned video as that would not have supported live face to face communication and interaction between Suchat and his visitors. Chuty asks spontaneous questions about some of the exhibits in the museum. Suchat will not have been able to pre-prepare the order of the captions. In this case, Suchat can introduce machine readable QR codes. QR codes were selected rather than other possible approaches (e.g. barcodes, RFID tags, image recognition, typing a code number) because they are simple, cheap, quick and work with smartphones using free software to provide a link to information on a mobile website (The Australian Hearing, 2004).

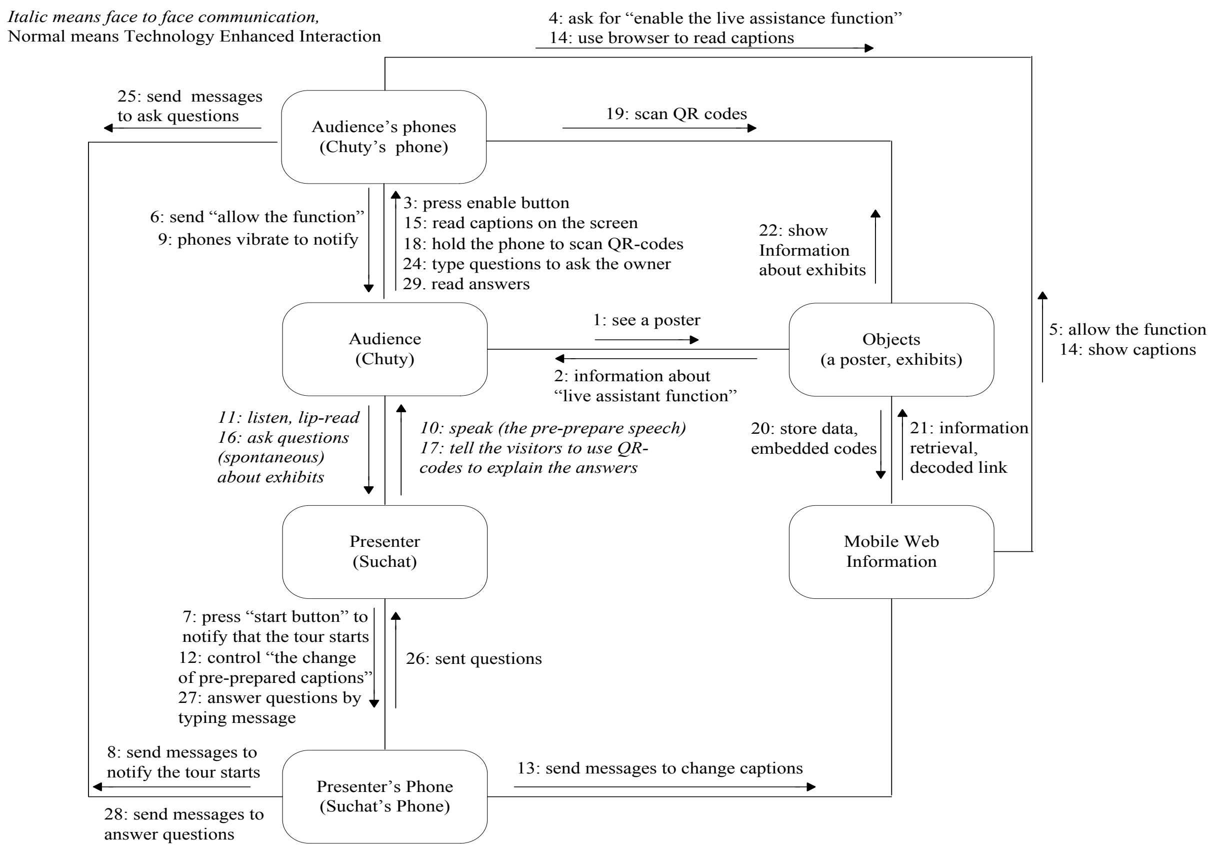

Figure 2. Interaction Diagram

Expert Validation and Review Findings

Six experts (with over five years of experience) were chosen to review and validate the TEIF and TEIF Method based on their expertise. Three experts were technology designer experts; the other three were accessibility experts. Both groups of experts were asked to validate and review the Framework and Method via an online survey. The technology designer experts focused on the TEIF and interaction diagram, whereas the accessibility experts were also asked to check the descriptions and explanations of the technology suggestions. The experts made suggestions for improvement to both the content and the system and their answers and suggestions are discussed below.

Expert Validation and Review of Technology Interaction Framework

The TEIF was successfully validated by the three technology designer experts. The experts' suggestions about the TEIF were: more detailed explanation of "object"; more examples of how weather condition could affect technology interactions; add People being aware of other interactions as sub-component to the context component; add identity of an object to the sub-component "Property"; explain perception that P-T-P interactions are not T-P interactions.

Expert Validation and Review of TEIF Method

The TEIF Method was successfully validated by the three technology designer experts and three accessibility experts. The expert's suggestions about the method were: more information and improve grammar/spelling/re-wording and layout/presentation; remove question 1 choice 'f'; explain relationship between requirements and subcomponents; investigate easier movement between sections; improve numbering and re-ordering of actions in Mobile Web Interaction Diagram; present framework method and process in easier smaller steps; consider the TEIF components as index for case based solutions.

Experimental Pilot User Studies

To help identify the best experimental design for an evaluation of the TEIF Method with designers, three software engineers conducted face to face interviews with the researcher playing the role of the client in order to investigate whether the engineers could gather and identify requirements in this "realistic" way. They found this task very difficult as they had not had experience of interviewing before. The researcher therefore decided on a different approach using a written document explaining the scenario for a task of evaluating requirements. The researcher developed and piloted two styles of presenting the scenario information: a "report" and an "interview transcript" as research had found that using an interview transcript with direct speech was more realistic and engaging than a descriptive document using indirect speech. The start of the transcript was:

Interviewer: *"Could you please tell me about your recent visitor?"*

Suchat: *"Chuty is a very successful Thai businesswoman in her 30s who has lived in Thailand all her life and only speaks Thai. She became hearing impaired in her twenties and depends completely on her hearing aids and lip-reading. She speaks clearly and I had no problem understanding her".*

The interview transcript was chosen to be used in the experiment as eight out of twelve participants preferred the interview transcript style to the report style. Six participants were asked to pilot the evaluate requirements task which involved evaluating the best 10 requirements from twenty-nine provided for a technology solution to the disability related problems they identified from the interview transcript. Modifications based on the feedback were clearer explanations, re-ordering the position in the list, and adding one more requirement to the list. To pilot the whole experiment eight software engineers at the university, both English native speakers and non-native speakers, were mixed equally between two groups and four participants were asked to use the TEIF Method while the other four were asked to use their preferred Other Methods.

The process for the pilot study was that the individual participant sat down with the researcher and applied the TEIF Method steps to complete the Evaluate Requirements Task and then the evaluate technology solutions task (evaluating three solutions for each of ten requirements by rating between 0 and 10) and finally answer a questionnaire. Participants were asked to do the tasks independently and the researcher only intervened to explain an instruction if a participant found it unclear. Improvements as a result of the pilot study included: providing a glossary to clarify words some non-native English speakers did not understand (e.g. shadow puppet, spontaneous speech); shortening and modifying the transcript to make it more realistic and more difficult to identify the requirements; instructions, requirements and transcript were made clearer to understand.

Experimental Design and Participants

The TEIF Method was designed to help improve a designer's awareness of interaction issues involving disabled people and their understanding of how environment context affects the accessibility of interactions and to provide a technology suggestions table to help with designing technology solutions. The purpose of this experiment was to evaluate the TEIF

Method by asking participants questions about the materials presented. Participants took between one hour and one hour and a half to complete the experiment. Thirty-six experienced software engineers were divided into two equal independent groups of eighteen participants with four English native speakers and fourteen non-native English speakers in each group. One group of the participants used the TEIF Method to complete the evaluate requirements task and the evaluate technology solutions task while the second group of participants used their preferred other methods to complete the evaluate requirements task and the evaluate technology solutions task and were then shown the TEIF Method. Both groups of participants were asked questions to check whether the TEIF Method helped in particular ways. The results of the questionnaire are presented and analysed in the next section while the results of the experimental tasks will be presented and analysed in a future journal article.

Questionnaire Results and Analyses

As the evaluate requirement task only involved evaluating requirements and the evaluate technology solutions task only involved evaluating designs, the questionnaires asked the participants' opinions about whether the TEIF Method would help them in gathering requirements and designing technology solutions when hearing impaired people were involved and, if further information was provided, also when other disabilities were involved.

Participants' profile

An independent sample t-test shows that there was no significant difference for participants in the two groups in the experience of designing software (4.89 years for TEIF Method group and 4.19 years for the Other Methods group) or designing technology solutions for disabled people (22% for the TEIF Method group, 17% for the Other Methods group).

Evaluation of TEIF Method Steps 1-4

There were eighteen participants who used the TEIF Method to do the experimental tasks. The results from the four steps involved were as follows:

Step 1: Identify interaction types

The interaction types: People-People (P-P), People-Objects (P-O), and People-Technology-People (P-T-P) were selected correctly by 100 % of participants, whereas the interaction types: People-Technology (P-T) and People-Technology-Objects (P-T-O) were selected correctly by 94 % of participants as shown in Table 3. The researcher checked the answers and if they got any wrong answers, the answers and explanation were shown and explained to them in order to make sure all participants understood the TEIF interaction types before moving to step 2.

Table 3. Number of participates who selected the right answers on step 1

Interaction Type	Number of participants who selected the right answer	Percent of participants who selected the right answer
People-People (P-P)	18	100.0
People-Objects (P-O)	18	100.0
People-Technology (P-T)	17	94.0
People-Technology-People (P-T-P)	18	100.0
People-Technology-Objects (P-T-O)	17	94.0

Table 4. Number of participants who selected the right answers on step 2

Question - answer	Number of participants who selected the right answer	Percent of participants who selected the right answer
1a	18	100.0
2b	18	100.0
3a	18	100.0
4a	17	94.0
5b	18	100.0
6b	17	94.0
7a	17	94.0
8a	17	94.0
9a	17	94.0
10a	18	100.0
10b	5	28.0
10c	12	67.0
10d	13	72.0
11a	16	89.0
11b	10	56.0
12a	18	100.0
12b	13	72.0
12c	14	78.0
13a	17	94.0
Mean	**16.28**	
Standard Deviation	**2.08**	

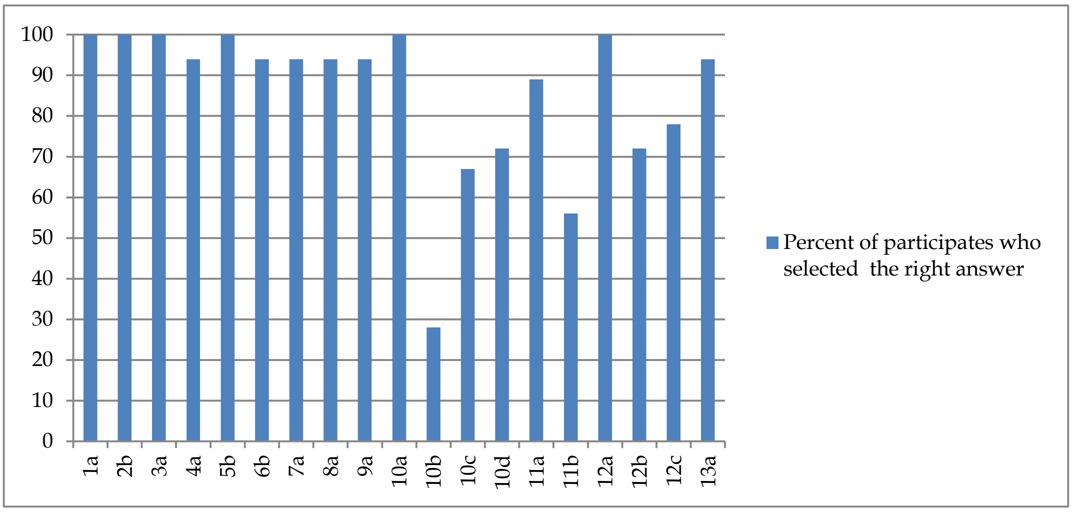

Figure 3. Percent of participants who selected the right answers in TEIF step 2

Step 2: Analyse how interactions are affected by hearing impairment

The participants were asked to read a transcript of an interview and answer the multiple choices questions that analysed how interactions were affected by hearing impairment. Where possible they underlined the words in the transcript sheet that helped them with each answer. There were thirteen questions in step 2 which participants had to complete. The questions helped participants analyse how interactions were affected by hearing impairment. The results of step 2, shown in Table 4 and illustrated in Figure 3 show that the majority of participants selected the corrected answer for every question apart from answer 10b.

Table 5. Number of participants who selected the right answers on step 3

Requirement number	Number of participates who selected the right answer	Percent of participates who selected the right answer
1	12	67.0
4	18	100.0
8	14	78.0
11	12	67.0
14	16	89.0
17	14	78.0
21	15	83.0
24	17	94.0
25	14	78.0
28	17	94.0
Mean for all items	**14.9**	
Standard Deviation	**2.80**	

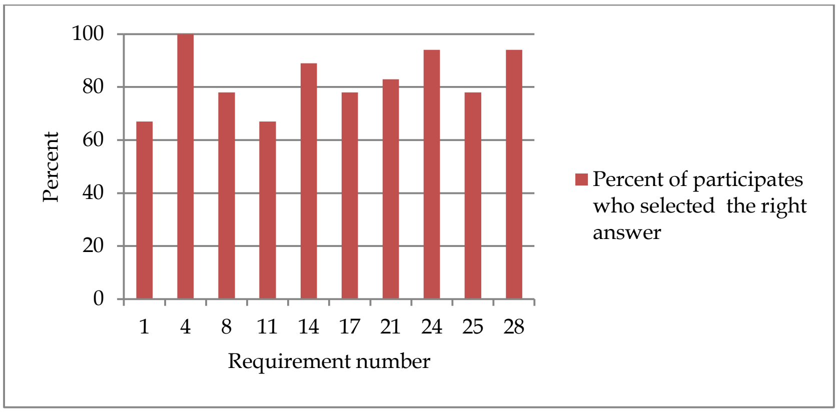

Figure 4. Percent of participants who selected the right answers in step 3

Step 3: Identify requirements

The participants from the TEIF Method group were asked to identify questions-answers that were related to the twenty-eight requirements. The ten answers (requirements 1, 4, 8, 11, 14, 17, 21, 24, 25, and 28) were provided in step 3 and which participants had to match with twenty-nine provided requirements and select only the best 10 requirements for a technology solution that solved the disability related problems identified from the interview transcript. The results of step 3, shown in Table 5 and illustrated in Figure 4, showed that the majority of participants selected the right answer for step 3.

Step 4: Identifying which technologies met each requirement

The technology suggestion table, which consisted of eleven technologies with descriptions, ticks and crosses, and the explanation of why ticks or crosses as shown in online tool tips, was provided as well as the ten requirements. The participants had to write the numbers of all the possible technology suggestions from the technology suggestion table provided which could be used to meet each of the ten requirements listed in the form provided in step 4. This TEIF step helped the participants to analyse the possible technologies which could be used in evaluating technology solutions related to the interaction when hearing impaired people were involved. The results of step 4 are shown in Table 6 and illustrated in Figure 5 and show that the majority of participants selected the right answers in step 4 apart from requirement 17 which was answered correctly by only 50% of participants.

Table 6. Number of participates who selected the right answers in step 4

Requirement	Number of participants who selected the right answer	Percent of participants who selected the right answer
1	13	72.0
4	13	72.0
8	16	89.0
11	11	61.0
14	11	61.0
17	9	50.0
21	10	56.0
24	12	67.0
25	16	89.0
28	11	61.0
Mean	**12.2**	
Standard Deviation	**2.348**	

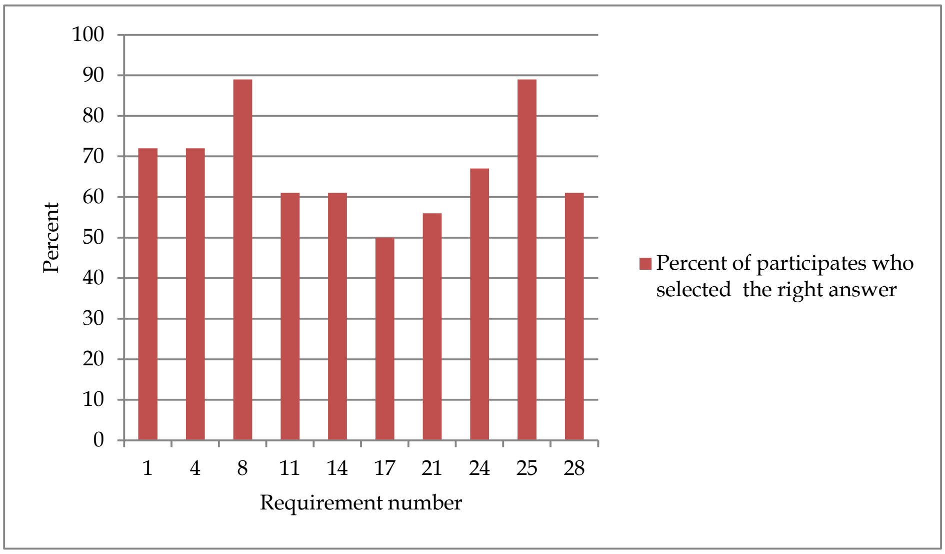

Figure 5. Percent of participants who selected the right answers in step 4

Questions asked to the TEIF Method group only

The participants from the TEIF Method group were asked to complete the questions related to the TEIF Method they used for the experiment. One sample t-tests on questionnaire results using a five point Likert scale where 5 meant they "strongly agreed" showed each mean rating for answers was a significantly difference greater than 3 with $p < .001$ and that:

- participants thought the TEIF Method helped in the evaluate requirements task to evaluate requirements for technology solutions to problems involving interaction with hearing-impaired people better than the Other Methods (mean = 4.5)
- participants thought the TEIF Method helped in the evaluate technology solutions task to evaluate technology solutions for problems involving interaction with hearing-impaired people better than the Other Methods (mean = 4.3)
- participants thought that the TEIF Method helped improve awareness of interaction issues involving hearing impaired people (mean = 4.4)
- participants thought that the TEIF Method helped improve understanding of how environment context affects interaction when hearing impaired people are involved (mean = 4.4)

- participants thought that the technology suggestions table helped identify technology solutions to issues involving hearing impaired people (mean = 4.4).

Questions asked to both group

The participants from both method groups were asked to complete the questions about their opinion in:

- gathering requirements to interaction problems involving hearing impaired people
- designing technology solutions to interaction problems involving hearing impaired people
- whether using the whole TEIF Method (both the evaluate requirements task and evaluate technology solutions task) would be needed for designing technology solutions
- gathering requirements to interaction problems involving other disabilities
- designing technology solutions to interaction problems involving other disabilities.

The one sample t-test was used to test whether the mean ratings were significantly greater than 3. There was a significant difference of mean ratings greater than 3 with $p < .001$ and participants thought that the TEIF Method would be helpful:

- in gathering requirements for technology solutions to interaction problems involving hearing impaired people (mean = 4.5)
- in designing technology solutions to interaction problems involving hearing impaired people (mean = 4.4)
- in gathering requirements to interaction problems involving a wider range of disabilities than just hearing impairment (mean = 4.5)
- in designing technology solutions to interaction problems involving a wider range of disabilities than just hearing impairment (mean = 4.3)
- participants thought that the whole TEIF Method would be needed for designing technology solutions (mean = 4.6).

The independent sample t-test statistic was used to test whether and how the TEIF Method helped in gathering requirements, and designing technology solutions with other disabilities where 5 meant they strongly agreed. The results showed that there was no significant difference of mean ratings between the two methods and participants in both groups thought that:

- the TEIF Method would be helpful for gathering requirements for technology solutions to interaction problems involving hearing impaired people (TEIF Method: mean = 4.6, Other Methods: mean = 4.5)
- the TEIF Method would be helpful in designing technology solutions to interaction problems involving hearing impaired people (TEIF Method: mean = 4.3, Other Methods: = 4.4)
- the whole TEIF Method would be needed for designing technology solutions (TEIF Method: mean = 4.6, Other Methods: = 4.5)
- the TEIF Method could help in gathering requirements to interaction problems involving a wider range of disabilities than just hearing impairment (TEIF Method: mean = 4.5, Other Methods: mean = 4.4)
- the TEIF Method could help in designing technology solutions to interaction problems involving a wider range of disabilities than just hearing impairment (TEIF Method: mean = 4.2, Other Methods: mean = 4.3).

Discussion

The expert validation and review of the TEIF by three designer experts, three accessibility experts and one HCI professor confirmed that a Technology Enhanced Interaction Framework (TEIF) could be developed regarding disabled people interacting with people, technologies and objects and that a TEIF Method could be developed building on this TEIF to help design technology solutions for disabled people interacting with people, technologies and objects. The questionnaire results confirmed that designers could use the TEIF Method to help with:

- evaluating requirements when designing technology solutions to interactions for disabled people with people, technologies and objects
- evaluating technology solutions when designing technology solutions to interactions for disabled people with people, technologies and objects
- gathering requirements when designing technology solutions to interactions for disabled people with people, technologies and objects
- designing technology solutions to interactions for disabled people with people, technologies and objects.

The results also confirmed that:

- the TEIF Method could help to improve their understanding of how environment context affects interaction when hearing impaired people are involved
- the technology suggestions table in the TEIF Method would be helpful for designing technology solutions to interaction problems involving hearing impaired people
- the whole TEIF Method was more helpful for designing technology solutions to interaction problems involving hearing impaired people than just using the technology suggestions table part of the method.

The results therefore suggest that the TEIF and TEIF Method have the potential to help designers develop mobile technologies that could enhance the accessibility of learning.

Conclusions and Future Work

The scenario and accessible mobile web learning solution described in this paper demonstrates how the TEIF and its associated method have the potential to help designers develop mobile technologies that could enhance the accessibility of learning by addressing the issue that, until now, there has been no framework to support technology designers and developers considering all of the interactions that might occur in face to face situations involving disabled people. The TEIF and TEIF Method have been validated and reviewed by technology designer and accessibility experts and an HCI professor. The TEIF Method was successful evaluated by technology designers. Questionnaire results from participants using or reviewing the TEIF Method to evaluate requirements and design solutions for problems involving interactions with hearing impaired people showed that they thought it helped them more than the Other Methods and that it would also help them to gather requirements and to design solutions for all disabled people if information about other disabilities than hearing impairment was provided.

The objective results and analysis from the experimental tasks investigating how the participants performed on the requirements evaluation and solutions evaluation tasks with the TEIF Method and the other preferred method will be presented elsewhere. These results will be compared with the participants' questionnaire answers which reflected what they thought about the TEIF Method. Future work includes extending the method and technology suggestions table to include information about disabilities other than hearing impairment.

References

Abowd, G. D., & Beale, R. (1991). Users, systems and interfaces: A unifying framework for interaction. In D. Diaper & N. Hammon (eds.), *Proceedings of HCI'91: People and Computers VI* (pp. 73-87). Cambridge: Cambridge University Press.

Bain, K., Basson, S., Faisman, A., & Kanevsky, D. (2005). Accessibility, transcription, and access everywhere. *IBM Systems Journal, 44*(3), 589-603.

Berne, E. (1964). *Games People Play – The Basic Hand Book of Transactional Analysis*. New York: Ballantine Books.

Broll, G., Siorpaes, S., Rukzio, E., Paolucci, M., Hamard, J., Wagner, M., & Schmidt, A. (2007). Supporting mobile service usage through physical mobile interaction. In S. Ceballos (ed.), *Fifth Annual IEEE International Conference on Pervasive Computing and Communications* (pp. 262-271). NY: IEEE.

Cambra, C. (2009). Comprehension of television messages by deaf students at various stages of education. *The American Annals of the Deaf*, 153(5), 425-434.

Cook, A., & Hussey, S. (1995). *Assistive Technologies: Principles and Pratice*. St. Louis, MO: Mosby.

Dix, A. (1994). Computer supported cooperative work - a framework. In D. Rosenburg & C. Hutchison (ed.), *Design Issues in CSCW* (pp. 23-37). Heidelberg: Springer Verlag.

Dix, A. (1995). Cooperation without (reliable) communication: Interfaces for mobile applications. *Distributed Systems Engineering*, 2(3), 171-181.

Dix, A. (1997). Challenges for cooperative work on the Web: An analytical approach. *Computer Supported Cooperative Work (CSCW)*, 6(2-3), 135-156.

Dix, A., Finlay, J., Abowd, D. G., & Beale, R. (2004). *Human-Computer Interaction*. Madrid, Spain: Prentice Hall.

Dror, I. E., & Harnad, S. (2008). *Cognition distributed: how cognitive technology estends our minds*. UK: John Benjamins, B.V.

Ellis, J. R., Ridolfi, G., & Zwirner, F. (1991). Groupware: Some issues and experiences. *Communications of the ACM*, 34(1), 39-58.

Flanders, N. A. (1960). *Interaction Analysis in the Classroom: A Manual for Observers*. Michigan: University of Michigan.

Foulger, D. (2004). *Models of the Communication Process.* Retreived 5 December 2014, from http://davis.foulger.info/research/unifiedModelOfCommunication.htm.

Gaines, B. R. (1988). A conceptual framework for person-computer interaction in complex systems. *IEEE Transactions on Systems, Man and Cybernetics*, 18(4), 532-541.

Harper, P., & Clark, C. (2002). *Mobile phones and Deaf people*. Australia Association of the Deaf. Retreived 5 December 2014, from http://deafaustralia.org.au/wp-content/uploads/MobileIssues.pdf.

Hsi, S., & Fait, H. (2005). RFID enhances visitors' museum experience at the Exploratorium. *Communications of the ACM*, 48(9), 60-65.

Isaacs, E., Walendowski, A., Whittaker, S., Schiano, D. J., & Kamm, C. (2002). The character, functions, and styles of instant messaging in the workplace. In C. Neuwirth & T. Rodden (eds.), *Proceedings of the 2002 ACM conference on Computer supported cooperative work* (pp. 11-20). NY: ACM.

Jetter, H.-C., Geyer, F., Schwarz, T., & Reiterer, H. (2012). Designing Collaborative Interactive Spaces. In G. Tortora, S. Levialdi & M. Tucci (eds.), *Proceedings of the International Working Conference on Advanced Visual Interfaces* (pp. 818-820). NY: ACM.

Klink, M. (2006). *The use of interaction methods in a blended learning environment: evaluating methods in blended learning environment in two courses of a Masters program at the university of south Australia, unit systems engineering & evaluation centre*. Master thesis University of Twente. Retreived 5 December 2014, from http://essay.utwente.nl/55969.

Larson, A. J, Raman, T. V., & Raggett, D. (2003). *W3C Multimodal Interaction Framework*. Retreived 5 December 2014, from http://www.w3.org/TR/mmi-framework.

Laurillard, D. (1993). *Rethinking university teaching: A framework for the effective use of educational technology*. London: Routledge.

Lee, D. S., Armitage, S., Groves, P., & Stephens, C. (2009). *Systems for supporting group learning*. Retrieved 22 April, 2014 from https://www.oucs.ox.ac.uk/ltg/teachingwithtechnology/CMC.pdf.

Merrill, M. D. . (2008). Reflections on a four decade search for effective, efficient and engaging instruction. In M. W. Allen (ed.), *Michael Allen's 2008 e-Learning Annual* (pp. 141-167). NJ: Pfeiffer.

Norman, D. A. , & Draper, S. W. (1986). *User Centered System Design: New Perspectives On Human-Computer Interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Petrie, H., & Bevan, N. (2009). The evaluation of accessibility, usability and user experience. In C. Stephanidis (ed.), *The Universal Access Handbook* (pp. 1-30). London: CRC Press.

Rukzio, E., Broll, G., & Wetzstein, S. (2008). The Physical Mobile Interaction Framework (PMIF). *Technical Report LMU-MI-2008-2*. University of Munich. Retreived 5 December 2014, from http://www.academia.edu/2679506/The_Physical_Mobile_Interaction_Framework_PMIF_.

Sacks, H. (1974). *An Analysis of the Course of a Joke's Telling in Conversation*. Cambridge: Cambridge University Press.

Sheng, L., & Xu, J. (2010). Using social software to improve learning performance of deaf university learner. In Proceedings of the *2nd IEEE International Conference on the Information Management and Engineering (ICIME)* (pp. 703-706). NY: IEEE.

Suebvisai, S., Charoenpornsawat, P., Black, A. W., Woszczyna, M., & Schultz, T. (2005). Thai automatic speech recognition. *Proceedings of the 2005 IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP '05)* (pp. 857-860). NY: IEEE.

Sung, Y.-T., Chang, K-E., Hou, H.-T., & Chen, P.-F. (2010). Designing an electronic guidebook for learning engagement in a museum of history. *Computers in Human Behavior,* 26(1), 74-83.

The Australian Hearing (2004). *Australian Hearing Annual Report 2003–04*. Chatswood, Australia: Australian Hearing.

Vyas, D., Dix, A., & Nijholt, A. (2008). Role of artefacts in mediated communication. In M. Czerwinski & A. Lund (eds.). Proceedings of CHI 2008 (pp. 1-8). Florence, Italy: ACM.

Wald, M. (2002). Hearing disability and technology. In L. Phipps, A. Sutherland, & J. Seale (eds.), *Access all areas: Disability, technology and learning* (pp. 19-23). University of Southampton: JISC Techdis Service with ALT. Retrieved 22 April 2014, from http://eprints.ecs.soton.ac.uk/10725.

Wang, S.-K. (2008). The effects of a synchronous communication tool (Yahoo Messenger) on online lerners' sense of community and their multimedia authoring skills. *Journal of Interactive Online Learning,* 7(1), 59-74.

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