LEANDRO LUQUE

**Collab4All: a method to foster inclusion in
Computer-Supported Collaborative Work**

Tese apresentada à Escola Politécnica da
Universidade de São Paulo para obtenção
do título de Doutor em Ciências.

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Concentration field:
Computing Engineering

Advisor:
Prof. PhD. Anarosa Alves Franco Brandão

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Paraphrasing Mahatma Gandhi: I am conscious of my own limitations and that consciousness is one of my strengths.

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This thesis is dedicated to:

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RESUMO

Nas últimas décadas, a área de Trabalho Colaborativo Apoiado por Computador avançou na proposição de teorias, técnicas e ferramentas para apoiar o trabalho colaborativo em diferentes contextos. No entanto, apesar dos avanços na área e suas subáreas, pessoas com deficiência ainda enfrentam desafios para serem incluídas em atividades colaborativas apoiadas por computador. Para participar desse tipo de atividade, espera-se que os envolvidos possuam certas habilidades e conhecimentos que podem ser afetados por deficiências. No início desta pesquisa de doutorado, estudamos meios para incluir um indivíduo cego em atividades colaborativas de modelagem realizadas como parte de um curso de Engenharia de Software ministrado pelo autor da tese. Como parte desse estudo, percebemos que pesquisadores e profissionais em geral não seguem métodos orientados à colaboração para abordar problemas de acessibilidade ao projetar sistemas de apoio ao trabalho colaborativo, também conhecidos como *groupware*. Nesse contexto, decidimos focar a pesquisa de doutorado no preenchimento dessa lacuna. Como resultado, desenvolvemos o Collab4All, um método para apoiar a identificação de possíveis desafios, bem como alternativas de solução, que podem surgir ao projetar *groupware* para incluir pessoas com deficiência. Como prova de conceito, com o objetivo de verificar se o Collab4All tem potencial prático, aplicamos o método ao cenário mencionado de inclusão de indivíduos cegos em atividades colaborativas de modelagem. Com base em nossas descobertas, documentamos algumas sugestões para pesquisadores e desenvolvedores que trabalhem neste cenário de aplicação. O presente documento contém informações detalhadas sobre este processo de pesquisa. Consideramos que o método proposto nesta tese, os resultados de sua aplicação e a ferramenta nela documentada, conhecida como Model2gether, são contribuições relevantes para a área de trabalho colaborativo apoiado por computador quando usado em cenários que envolvem pessoas com deficiências.

Palavras-chave: CSCW, Deficiência, Inclusão, Colaboração, Cooperação, Collab4All, Método, Cegueira, Deficiência Visual, Computação, UML, Software, Sistema, Model2gether.

ABSTRACT

During the last decades, the research field of Computer-Supported Collaborative Work has made impressive progress in proposing theories, techniques, and tools to support collaborative work in different settings. Nevertheless, despite the advances in the field and its branches, individuals with impairments still face inclusion challenges when performing computer-supported collaborative activities. In order to take part in such type of activities, individuals are expected to have skills and knowledge that may be affected by impairments. In the beginning of this PhD research, we studied means to include an individual with blindness in diagram-based activities conducted as part of software engineering lectures taught by the thesis author. As part of that, we noticed that researchers and practitioners generally did not follow any collaboration-oriented method to address accessibility issues when designing or redesigning collaboration supportive systems, also known as groupware. In this context, we decided to focus our attention on this gap. As a result, we developed Collab4All, a method to support the identification of potential challenges as well as alternative solutions that may arise when designing or redesigning accessible and inclusive groupware. As a proof of concept, we applied Collab4All to the aforementioned scenario of including individuals with blindness in diagram-related learning activities. Based on our findings, we documented some suggestions to researchers and developers working in this application scenario. The present document contains detailed information about this research process. We consider that the method proposed in this thesis, its application results and the groupware we developed, named Model2gether, are relevant contributions to the field of computer-supported collaborative work involving people with impairments.

Keywords: CSCW, Impairment, Disability, Inclusion, Collaboration, Cooperation, Collab4All, Method, Blindness, Visual Impairment, Computing, UML, Software, System, Model2gether.

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LIST OF ABBREVIATIONS

2D two dimensional.

3D three dimensional.

AWMo Accessible Web Modeler.

BPMN Business Process Model and Notation.

CASE Computer-Aided Software Engineering.

CCmI Collaborative Cross-modal Interfaces.

CSCCL Computer-Supported Collaborative Learning.

CSCW Computer-Supported Collaborative Work.

CSIC Computer-Supported Intercultural Collaboration.

DAO Data Access Object.

DFD Data Flow Diagram.

DSL Domain Specific Language.

DSR Design Science Research.

E-MAGModelo de Acessibilidade em Governo Eletrônico (In Portuguese).

EPF Eclipse Process Framework.

EPIC Executive-Process Interactive Control.

ERD Entity-Relationship Model.

HCI Human-Computer Interaction.

HTML HyperText Markup Language.

IDE Integrated Development Environment.

IEC International Electrotechnical Commission.

HUTN Human-Usable Textual Notation.

ISO International Organization for Standardization.

IRUP IBM Rational Unified Process.

ISO International Organization for Standardization.

MHP Model Human Processor.

NATO North Atlantic Treaty Organization.

NVDA NonVisual Desktop Access.

OCR Optical Character Recognition.

OMG Object Management Group.

OMT Object Modeling Technique.

OOSE Object Oriented Software Engineering.

SVG Scalable Vector Graphics.

TeDUB Technical Diagram Understanding for the Blind.

TTS Text-to-Speech.

UML Unified Modeling Language.

US United States

USP Universidade de São Paulo (In Portuguese).

W3C World Wide Web Consortium.

WAI Web Accessibility Initiative.

WBS Work Breakdown Structure.

WCAG Web Content Accessibility Guidelines.

WHO World Health Organization.

XMI XML Metadata Interchange.

XML eXtensible Markup Language.

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PART I

INITIAL CONSIDERATIONS

1 INTRODUCTION

This chapter presents an introduction to the research documented in this thesis. It begins presenting a background on the roots of *Computer-Supported Collaborative Work* (CSCW) (Section 1.1). In the same section, it discusses the problem addressed in this research, related to the inclusion of individuals with impairments in CSCW. Afterwards, it delimits the problem and highlights its relevance (Section 1.2), as well as presents the research objectives (Section 1.3). Finally, it summarizes the main contributions of this research (Section 1.4) and outlines the remaining document chapters (Section 1.5).

1.1 Background

The early years of modern computing were mainly focused on "machinery for calculation", involving efforts to break codes, calculate ballistic trajectories, among others (WINOGRAD, 1997). Over time, the reduction in hardware size and cost, and the increase in software capabilities broadened the field horizons (CERUZZI et al., 2003). Progressively, the mainstream focus shifted to supporting and facilitating other human activities.

Aligned with this movement, Irene Greif and Paul Cashman organized a workshop in 1984 on how to support multiple individuals working together using computer systems (BANNON; SCHMIDT, 1989). This is known to be the first event on CSCW and the occasion in which the term was coined (SCHMIDT, 2012). A few years later, CSCW had established itself as an independent research field and ever since it has expanded and matured. This expansion brought to the field contributors and contributions from many different areas and gave a multidisciplinary nature to it (CRUZ et al., 2012). In general, the research in CSCW has focused on developing theories of computer-supported collaborative work, as well as tools that facilitate collaboration among participants of group activities (HAMALAINEN et al., 1991; SWIGGER; THOMAS; BRAZILE, 1993). Its application to specific domains resulted in some field branches with many intersections but also different research and development paths. For instance, CSCW

is known as *Computer-Supported Collaborative Learning* (CSCL) when applied to education (LIPPONEN; HAKKARAINEN; PAAVOLA, 2004) and as *Computer-Supported Intercultural Collaboration* (CSIC) when applied to the enhancement and enrichment of effective intercultural communication and collaboration (VATRAPU; SUTHERS, 2010).

Nevertheless, despite the advances in CSCW and its branches, individuals with impairments still face challenges to perform some sort of computer-supported collaborative activities (ANTIA et al., 2011; BAGATELL et al., 2010; BURKHAUSER; DALY, 2011; EIDE; INGSTAD, 2017; KUNZ et al., 2014). In order to take part in such type of activities, individuals must be able to: (i) communicate with others; (ii) be aware of and manipulate the resources being used and their feedback; (iii) be aware of and manipulate the artifacts (input, deliverable, and work products) and changes made to them (PREECE; SHARP; ROGERS, 2015), among others. On their foundation, these requirements depend on knowledge as well as motor and cognitive-related skills such as arm movement, perception, recognition, and memorization. Impairments may influence knowledge and these skills and, consequently, pose challenges to computer-supported collaborative activities. Moreover, different physical and mental conditions may result in distinct mental and user models, which may also affect CSCW.

We personally experienced a CSCL scenario in which accessibility was an issue - a series of software engineering lectures involving sighted learners and a learner with blindness. The lectures used the *Unified Modeling Language* (UML) (BOOCH; RUMBAUGH; JACOBSON, 2006) to present object-oriented analysis and design concepts and practices. Adaptations on the lectures style were required. For instance, the use of a presentation tool in which diagrams were shown on the learners' computer screen was ceased because it was not accessible for the learner with blindness. In addition, the activities that were usually conducted with spatial distance among the learners (e.g. virtual learning lectures) created additional challenges.

This experience motivated us to research and develop groupware - CSCW supportive systems - related to the inclusion of individuals with blindness in such a collaborative setting. As part of that, we noticed that researchers and practitioners generally did not follow any collaboration-oriented method as part of the (re)design of accessible and inclusive groupware. This perception was validated through a systematic literature mapping (see Appendix A) and was also reported by other authors'

review (ANGKANANON; WALD; GILBERT, 2015). In general, accessibility was addressed in groupware (re)design through: (i) frameworks that do not take into consideration all collaboration aspects; and (ii) traditional accessibility models used for non-collaborative software. Authors experience and findings of similar studies also contribute to the way they addressed this issue. A problem with such approach is the risk of missing important aspects that have to be taken into consideration.

As one may find distinct definitions of accessibility, it is important to highlight that the definition we adopt in this work is aligned with one of the term definitions proposed in ISO/IEC 25010:2011 (ISO, 2011b), item 4.2.4.6. It states that

"... accessibility can be specified or measured as the extent to which a product or system can be used by users with specified disabilities to achieve specified goals with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use" (ISO, 2011b).

In this context, we decided to focus our attention on supporting research and development in CSCW and its branches involving people with impairments. The analysis of specific collaborative activities involving people with particular impairments and the development of tools to support such activities were among the possible approaches to conduct this research. Another possible approach was looking for means to assist researchers, practitioners, and developers with the identification of potential challenges as well as alternative solutions that may arise from using groupware including people with impairments. Among these approaches, we decided to turn our attention to the latter, given its generality.

As part of the research process, we noticed that the *Model Human Processor* (MHP) (CARD, 2017) - a model of how humans acquire, process and store information - could be used as a basis for analyzing how impairments may impact collaborative activities. MHP has been used in the *Human-Computer Interaction* (HCI) field since its early days to evaluate human performance in tasks. It considers humans as information processors and seeks to understand the different cognitive processes involved in a task and how they interact and influence humans' perception and actions.

1.2 Problem Delimitation and Relevance

Hence, the problem we addressed in this research is the gap of collaboration-oriented methods to support the (re)design of accessible and inclusive groupware. Of particular interest is the problem of identifying challenges and alternative solutions that can arise from using groupware including individuals with impairments. Furthermore, we focused on how a solution for this problem could support the evaluation of a software we developed to include individuals with blindness in diagram-based activities - as aforementioned, the context that motivated us to conduct this research.

According to the *World Health Organization* (WHO) (2011), 1 billion people worldwide have a disability, which corresponds to 15% of the world's population. In Brazil, according to a recent analysis (MICAS; GARCEZ; CONCEICAO, 2018), there are about 14 million people with severe disabilities, or 6.7% of the population. Many of the activities these individuals perform have a collaborative nature. When considering only those supported by computers, one can mention: collaboratively creating and editing documents (TAMMARO et al., 1997) using online text editors like Google Drive, Office online or ShareLaTeX; attending online classes (LI, 2009); communicating (KANJO; ASTHEIMER; MARSHALL, 2004), among others.

Performing user tests and experiments involving individuals with impairments is generally expensive. It sometimes requires a series of environment and resource adaptations, in addition to personnel training. Even a small pilot test may be costly. Considering that, it is important to reduce the chances of not being able to conduct a collaborative activity involving individuals with impairments due to the lack of accessibility of a groupware. From another perspective, it is desired to address as much aspects as possible in tests and experiments.

In summary, the inclusion of people with impairments in collaborative activities is relevant because of: (i) the volume of people potentially affected by the lack of accessibility of computational resources; (ii) the predominance of the use of computational tools in modern society; and (iii) the volume of collaborative activities that anyone can participate. In addition to that, it is a relevant issue because every person, regardless of any impairment, should be able to fully participate in society. Certainly, there are activities inappropriate for specific groups of people due to any peculiarity. Nonetheless,

lots of individuals are still unnecessarily segregated from collaborative activities, such as education (COLE, 2017) and certain types of occupation (BARAK, 2016).

1.3 Objectives

In this context, the general objective of this research is to contribute to the field of CSCW when considering the inclusion of individuals with impairments.

The specific objectives of this research were:

- propose and validate means to support the inclusion of individuals with blindness in diagram-based collaborative activities;
- to define a method to support the identification of potential challenges and alternative solutions that may arise from using groupware including people with impairments;
- to analyze the method viability through a proof of concept in a diagram-based collaborative scenario.

1.4 Contributions

We consider that the method proposed in this thesis is a relevant step to support (re)design of accessible and inclusive groupware when involving individuals with impairments. After developing the method, we used it to evaluate a groupware we developed to support the inclusion of individuals with blindness in collaborative diagram-based activities. As part of this evaluation, we conducted a series of user studies. The results indicate that participants with blindness face an information overload scenario and require moments of interruption in awareness and communication to concentrate, to decide about their actions and to update the object under screening. Based on users' feedback, we give some suggestions to present awareness and communication information to individuals with blindness in collaborative activities. It is our claim that the method, the groupware and the application results are relevant to the research area of computer-supported collaborative work and to the development of solutions that promote a better inclusion in education programs and in industry.

1.5 Organization

This document is organized in 4 parts, which comprehend 12 chapters. Part I is composed of this introduction and a chapter that describes the research method adopted to conduct this research. Part II, Background, contains 4 chapters describing fundamentals needed to understand the proposed method. At the beginning of Part II, we detail what each chapter covers. Part IV, Research Development and Results, is composed of 5 chapters, in which we describe our achievements while conducting this research. It begins with evidences about the importance of providing solutions to support inclusion in computer-supported collaborative activities (chapter 7), followed by the description of the development and evaluation of a groupware to support collaborative modeling activities (chapters 8 and 9). This part ends with the description of the proposed method (chapter 10) followed by a proof of concept to assure its viability (chapter 11). Finally, Part IV, Final Considerations, is composed of only one chapter, where we present the conclusions and future research opportunities that can be addressed. Some appendices are provided presenting details of some content summarized along the text.

2 RESEARCH METHOD

This chapter presents an overview of the method we followed in this research. The next two sections sketch its iterations. The method described here was submitted to and approved by the Hospital Universitário Research Ethics Committee of the *Universidade de São Paulo (In Portuguese)* (USP) - identification CAAE 49264815.3.0000.0076.

2.1 Design Science Research

In order to achieve the objectives established in this research, we followed a method inspired by *Design Science Research* (DSR) (PEFFERS et al., 2007). DSR is an engineering-oriented problem solving process that comprises 6 main steps: (i) Identify problem and motivation; (ii) Define requirements for a solution; (iii) Design and develop an artifact that fulfills the solution requirements; (iv) Demonstrate the solution; (v) Evaluate the solution; and (vi) Communicate the results. The rationale behind DSR is to improve a scenario by introducing new and innovative artifacts/processes for building these artifacts (SIMON, 1996). For sake of organization, we present the steps (iv) and (v) as a single one. Several iterations of a DSR process may be conducted until the achievement of the problem solution. Figure 1 shows the DSR methodology process model, as stated by Peffers et al. (PEFFERS et al., 2007).

The research method followed to conduct this thesis comprised 2 DSR iterations. At the first iteration, the initial problem was including individuals with visual impairment in collaborative modeling activities using groupware. After walking through all DSR activities at the first iteration and receiving feedback from the research community, we realized that the absence of a method to support the (re)design of groupware was a problem to be addressed. A second iteration was conducted and Collab4All was proposed as a method to foster inclusion in CSCW. It was validated by the redesign of Model2gether, the groupware produced along the first iteration.

As these iterations involved several steps that produced intermediary results, each of them with a large volume of information, we decided to present details about itera-

Figure 1: Design Science Resource Methodology Process Model (Source: Peffers et al. (PEFFERS et al., 2007)).

tions in Part III.

2.2 DSR first iteration

At the first iteration, we identified and explored the problem through literature reviews, tools review, and a survey with questionnaires. These tasks compose the 1st iteration's first activity (Figure 2). Results of this activity are presented in chapter 7. Then, we defined requirements for a solution and verified that none of the found tools fulfilled all the requirements. These tasks compose the 1st iteration's second activity (Figure 2). In sequence, we implemented this solution as a web-based software, named Model2gether, and tested it through user tests. The results obtained were communicated to the research community via conference presentations and publications. These tasks compose the 1st iteration's third, fourth and fifth activities (Figure 2), and are presented in chapters 8 and 9.

2.3 DSR second iteration

Following the DSR process illustrated in Figure 1, we started the second iteration by updating the literature review and combining its findings with the results of the first iteration. Based on our findings, we defined Collab4All, a method to foster inclusion of individuals with impairments in CSCW. In order to define the requirements for a newer version of Model2gether, we applied Collab4All. These tasks composed the first and second activities of the DSR 2nd iteration (Figure 3). In fact, new requirements for Model2gether were defined based on the potential challenges identified by applying Collab4All in an inclusion scenario using Model2gether. The effective redesign, development, demonstration & evaluation of Model2gether involved the third and fourth activities of the 2nd iteration (Figure 3). It is our claim that the result of Model2gether evaluation is a proof of concept for Collab4All viability.

Figure 2: Activities conducted at the first iteration of the research method (Source: author).

Figure 3: Activities conducted at the second iteration of the research method (Source: author).

PART II

BACKGROUND

Part II Overview

This part of the thesis describes fundamentals that we consider essential for understanding Collab4All. It begins with concepts and models related to Computer Supported Collaborative Work (chapter 3), the field in which the proposed method is embedded. In the follow, we discuss about accessibility and groupware development, to provide foundations to our technological decisions (chapter 4). Then we describe some Human Information Processing Models, their relation to Human Computer Interaction and their components. A relation between collaboration and the human information processing components is also presented (chapter 5). Finally, we close this part with a chapter about graphical models and computing to clarify the knowledge domain we will address along the thesis (chapter 6).

3 COMPUTER-SUPPORTED COLLABORATIVE WORK

This chapter discusses the terminology related to the field of CSCW (Section 3.1), the components of collaboration (Section 3.2), and the social mechanisms involved in collaborative activities (Section 3.3). It ends discussing the main collaboration models used to study collaborative activities (Section 3.4). This knowledge is essential to understand the method we propose in this research and how it supports the different aspects involved in collaborative activities.

3.1 Definitions and Terminology

According to Schmidt and Bannon (1992), the field of CSCW seeks to understand the nature and requirements of collaborative work aiming at designing supportive computational technologies.

As mentioned in the introduction, the CSCW field has its roots in the 1980s and since then has received contributions from many different areas. Maybe due to its multidisciplinary nature, there is no consensus on the field boundaries. Even the word 'collaborative', used in the field name, is subject of debate. As mentioned by Greenberg (1991a), one can find examples of research carried out under the term CSCW that does not fit exactly the terms' constituent words.

Computer: technologies other than computers (such as video) are considered within the CSCW domain; *Supported*: while support may be offered to the group as a whole, activities of particular individuals may be disrupted; *Collaborative*: the social process can include not only collaboration, but aggression, competition, and loose coordination; and *Work*: casual and social interaction must be supported as well, for they are considered a vital precursor to the work process (GREENBERG, 1991a).

Therefore, it is important to make clear our understanding of the terms used in the field.

Firstly, it is important to highlight that the constituent words of the field acronym sometimes include the term *collaborative* (ESERYEL; GANESAN; EDMONDS, 2002) and other times the term *cooperative* (BORGHOFF; SCHLICHTER, 2000).

The term *cooperation* comes from the Latin word *cooperātiō* (co- "together", operari- "operate"), literally meaning operate together (WEEKLEY, 2012). It was the term chosen by Irene Greif and Paul Cashman for the workshop they organized in the 1980s. When they choose *cooperative work* to constitute the name of the workshop, the expression had already a long history in the social sciences (SCHMIDT; BANNON, 1992). A general definition of *cooperative work* comprises the notion of multiple individuals working together in a conscious way in the same process or in different but connected processes. At the core of this definition is the notion of interdependence in work, not only in terms of sharing resources but in terms of one relying on the quality and timeliness of others' work. (SCHMIDT; BANNON, 1992). Furthermore, in spite of the goals of the underlying processes, participants may have different individual goals (BANNON; SCHMIDT, 1989). Also, this definition does not imply any specific form of interaction or organization such as mode and frequency of communication, equality of status, among others.

When we use the term *cooperation*, we mean the work carried out jointly by the participants of collaborative activities, as defined by Gerosa et al. (2006). The term *collaboration* is used here as a broader concept encompassing the work itself (the co-operation) and other orthogonal aspects to the work, such as awareness, coordination, and communication.

Another term used in the field is *groupware*. It was originally defined by Peter and Trudy Johnson-Lenz (1998) as intentional group processes plus software to support them. In this work, we adopt the definition by Ellis et al. (1991) according to which groupware refers to any computer-based system that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment (ELLIS; GIBBS; REIN, 1991).

3.2 Components of Collaboration

A collaborative work comprises activities, sub-activities, both non-atomic executions, and tasks, atomic executions - while a task is considered atomic, it may sometimes be decomposed in steps. These elements have aligned goals. Tasks are performed through the participation of different people playing a variety of roles. Participants may use resources (e.g. tools) and input artifacts to perform tasks. Moreover, they can produce new artifacts or update existing ones (e.g. deliverables or working products) as a result of task execution. Artifacts may be based on templates. A sequence of tasks may be categorized in two groups regarding the interdependence among its constituent tasks: procedural and nonprocedural. The former comprehends those that must be performed in a fixed or variable sequence to be properly accomplished. The latter, in turn, are those that may be executed in any order. Figure 4 illustrates the relationships between these elements using the UML class diagram notation. Properties were omitted in order not to overload the representation with information. The social mechanisms are orthogonal concepts of the work itself. The next section discusses these concepts.

3.3 Social Mechanisms of Collaboration

There are three main types of social mechanisms that arise in a collaborative work (PREECE; SHARP; ROGERS, 2015):

- Conversational mechanisms: to facilitate the flow of speech and to help overcome breakdowns along it;
- Coordination mechanisms: to allow people to work together and interact;
- Awareness mechanisms: to find out what is happening, what others are doing, among others.

Conversational mechanisms are related to communication. When partially mediated through computer systems, they can be classified into three main categories: people-people, people-technology, and people-technology-people. This classification

Figure 4: The structure of a collaborative work with implicit social mechanisms (Source: author).

is based on the work of Angkananon et al. (2015), excluding two categories: people-object and people-technology-object, since we understand these are part of awareness.

People-people communication happens both verbally (speak, listen) and non-verbally (lip-read, smile, touch, gesture, node). People-technology communication involves: (i) commands/orders, from people to technology; (ii) images, sounds, vibration and related feedback from technology to people. When computer systems mediate communication between people - people-technology-people -, the other two aforementioned communication categories happen.

Regarding coordination mechanisms, one can establish a classification into two categories: master-slave and master-master (KI; KLASKY, 1998). In the former, one of the participants takes the activity control, while in the latter participants share the activity control. In the case of a master-master coordination, it is important to define whether participants may work in parallel in different parts of the artifacts. Furthermore, it is possible to establish lock rules at different levels, to prevent two or more participants from modifying the same part of an artifact.

Coordination comprehends the definition, understanding and processing of a set of rules, which are generally defined and agreed by participants, and may be implicit within the activity context. A lecture, for example, has some implicit rules regarding the moments in which learners can make questions and interact with others. The rules may be defined prior to the activity or be created during the activity, in response to what participants consider appropriate to do.

As quoted by Machado et al. (2016), the success of collaborative tasks is related to the capacity of participants to be aware of other people's actions so that they can realize their own action. This is part of what is known as awareness. For instance, when a participant is modifying an artifact using resources, it is important to be aware of the results of each action in the artifact. Furthermore, it is important to be aware of the results of other participants' actions in order to coordinate and define the pace of the work. Among awareness-related questions are (GUTWIN; GREENBERG, 1999):

- (i) Is anyone in the workspace?

- (ii) Who is participating?
- (iii) What are they doing?
- (iv) What goal is that action part of?
- (iv) What object are they working on?
- (v) Where are they working? Where are they looking?
- (vi) When did an event happen?
- (vii) How did that operation happen?
- (viii) How did this artifact come to be in this state?

3.4 Collaboration Models

Collaboration is generally studied through collaboration models. Such models usually decompose collaboration or collaborative activities in components (communication, coordination etc.) as well as establish the dependencies and relationships among them. Collaboration models can be used for understanding (ZAMZURI; WANADNAN, 2007), classifying (BORGHOFF; SCHLICHTER, 2000), and assisting the implementation of collaborative systems (CALVARY; COUTAZ; NIGAY, 1997; LAURILLAU; NIGAY, 2002). Next, we present some collaboration models that we used as basis in our method.

Ellis et al. (1991) proposed the decomposition of collaboration in three main components: coordination, cooperation, and communication (Figure 5). That publication was the origin of a model known as 3C, used to study different aspects of collaborative work and supportive systems (FUKS et al., 2005; GADELHA et al., 2009; STEINMACHER; CHAVES; GEROSA, 2010; OLIVEIRA; GEROSA, 2011; MEDEIROS et al., 2012).

In 3C, the work carried out jointly by the participants of the collaborative activity is represented by the Cooperation component. This work is carried out in a shared space where participants interact physically or virtually. It involves acting on objects of cooperation. An object can be, for example, a mindmap (BUZAN; BUZAN, 2010) created jointly by the participants. Before, during and after the collaborative work,

Figure 5: A representation of the main components of the 3C Model (Source: Fuks et al. (2005))

communication between the participants may be necessary in order to exchange messages, negotiate commitments, define responsibilities, roles, and tasks. This aspect is represented in the model through the Communication component. Commitments generated via communication and due to prior knowledge assist in the coordination of work - Coordination component. It is a two-way path, since coordination influences the moments in which communication takes place. Coordination organizes the team assigning tasks, setting orders, and specifying boundaries. Coordination also involves the articulation of different tasks. Another model (implicit) component is the awareness. Through awareness, a participant have access to information necessary for conducting the work.

Focusing on systems architecture and implementation, Calvary et al. (1997) proposed the Clover model. The authors organize systems to support collaborative activities in three specific spaces: production, coordination, and communication. The production space denotes the objects that model the collaborative elaboration of artifacts, such as a document. The coordination space comprises dependencies between activities. The communication space supports face-to-face communication, both synchronous and asynchronous.

Neale et al. (2004) bring awareness to the center of attention. The authors propose a collaboration model that focuses on the underlying relationships related to distributed group work processes. According to the authors, communication, coordination and engagement are the basis for understanding how groups work. The authors also highlight

the contextual factor. People manage the context and social aspects that binds them in very complex but subtle ways. Besides, they use the context to understand how to organize their individual efforts within the framework of their social interactions as part of groups. However, they do this largely as background activity, without being fully aware of how the context shapes their behavior. The context is composed of the activities themselves. It is more than just a container that frames activities. It involves the internal states of the actors themselves and develops dynamically as part of common interactions with others. Second, the context is defined by some questions:

- (i) Who is present?
- (ii) What are they doing?
- (iii) Are they bored?
- (iv) Who else is there?
- (v) What is their relationship to others?
- (vi) What are the artifacts of interest?
- (vii) What is happening around people?
- (viii) What are the subtle circumstances of people's lives and situations outside the immediate context that shapes their behavior in the current situation?

The authors state that without this information it is hard to understand why people do what they do, especially when they do things contrary to what is expected or planned.

4 ACCESSIBILITY AND GROUPWARE DEVELOPMENT

Software quality has been a major concern in the computing field since the 1968/69 NATO Software Engineering conferences (HOFMAN, 2011), in which the term *software engineering* was born. At that time, the motivation for pursuing quality was what is known as *software crisis* - a period in which only about 5% of the software products were used without or with few changes. About 95% of what was produced in the field were abandoned, remade, or delivered but never used (ASSIMAKOPOULOS, 1997). Nowadays, the main engines for quality-related concerns are market competition and the central role computing plays in modern society - poor software quality may affect millions of people (QASYMPHONY, 2016).

The pursuit of quality has resulted in various software development methodologies, methods and process models/frameworks (BECK, 1999; BOEHM, 1988; JACOBSON; BOOCH; RUMBAUGH, 1999; ROYCE, 1987). As some of these terms are sometimes used interchangeably, we consider relevant to present the definition of *method*, since we propose one as a result of the research work.

A method is understood in this work as a set of information, principles, activity-related content, and guidelines that may be used to tackle a specific concern of software development.

The proper selection and usage of methodologies, methods, and process models/frameworks contribute, together with people and tools, to the overall quality of a software product (PRESSMAN, 2014). The general idea behind software development is that it is necessary to understand and validate the problem that must be solved or the opportunity that must be addressed at the beginning of the process. This problem exists in a specific domain, that must also be understood. Information about the problem domain fosters requirements gathering and specification. Before implementing a requirement, it must be analyzed and detailed. In order to form a final product from the different software parts and reach desired quality attributes, it must follow a design and architecture. All these activities require validation and verification. As a final result, the software must be installed in a proper infrastructure. Different methodologies,

methods, and process models/frameworks, address this process distinctly, but with an aligned view. Some of them as sequential activities, others as iterative. Some with a strong focus on code and others on planning.

In this context, accessibility and inclusion are addressed in software development in different moments. They must initially be specified as a set of requirements. Thus, they must be included in the software design. And finally, they must be evaluated during and after development.

Various accessibility models and guidelines have been proposed for software development (BRAZIL, 2011; ISO, 2011b; SILVEIRA; HEIDRICH; BASSANI, 2007; W3C, 2008). The next section presents some of the main used ones.

4.1 Accessibility models and guidelines

ISO/IEC 25010:2011 standard (ISO, 2011b), last reviewed in 2017, define two complementary quality models for system and software, one focused on quality in use and other on product quality. The former comprises five characteristics, subdivided in sub-characteristics, which relate to the outcome of interaction when a product is used in a particular context of use. The latter comprises eight characteristics, also subdivided in sub-characteristics, which relate to static and dynamic properties of computer systems. These models can be used to specify and evaluate software product quality. Accessibility is categorized in this models as a sub-characteristic of usability. Unfortunately, these accessibility-related concerns are recent and little widespread.

Existing standards for the area are generally related to web applications and to public authority. In 1998, Section 508 determined that all electronic content of federal agencies in the *United States* (US) should be provided in a format accessible to people with impairments. In 1999, the *World Wide Web Consortium* (W3C) created the *Web Accessibility Initiative* (WAI), which was formed by working groups to develop guidelines for ensuring the accessibility of web content. In May of that year, the group published the *Web Content Accessibility Guidelines* (WCAG), "W3C Recommendation Status", currently in version 2.1. In the same year, the government of Portugal defined accessibility rules for the web and ended up influencing the entire European Union in the adoption of what was known as "e-Europe 2001". Based on WCAG, the Brazil-

ian government proposed a set of guidelines for web development, named *Modelo de Acessibilidade em Governo Eletrônico (In Portuguese)* (E-MAG). It must be used as a reference for governmental websites.

WCAG has 13 guidelines, organized under 4 principles: perceivable; operable; understandable; and robust. For each guideline, there are testable success criteria, which may be at three levels: A, AA, and AAA. For instance, the guidelines present recommendations on how to use *HyperText Markup Language* (HTML) to develop accessible web-pages, such as: *use the aria-describedby property to provide a descriptive label for user interface controls*. Each guideline has information about its applicability, a description, examples, resources that may be consulted, and tests.

Accessibility is generally evaluated through automatic tools, usability tests, and heuristic evaluations (PREECE; SHARP; ROGERS, 2015).

4.2 Accessibility of groupware for individuals with impairments

Some frameworks have been proposed to support the development of groupware (COSQUER et al., 2000; GREENBERG, 1991b; KERBRAT; ATALLAH, 1995; SAGE, 2001; SCHOEBERLEIN; WANG, 2009). These frameworks focus on system architecture aspects to design groupware.

IMS Global Learning Consortium proposed guidelines for assessing CSCL accessibility (CONSORTIUM et al., 2002). It includes common accessibility problems for synchronous and asynchronous groupware. However, it is mainly focused on accessibility for individual activities and does not give attention to collaboration components. For instance, examples of accessibility problems for audio-conferencing include: (i) audio output that is inaccessible to users who are deaf or who have profound hearing loss; (ii) speech input that may be difficult for users with speech disabilities; (iii) some exclusively mouse-driven functions; (iv) fast pace of conversation that may limit access by users who communicate slowly.

The focus on individual accessibility is based on an idea that if mutually coherent interfaces are available for individuals with and without impairments, collaboration is ensured. This is the approach of some studies in the field (MYNATT; WEBER, 1994;

PETRIE; MORLEY; WEBER, 1995; SAVIDIS et al., 1996). Mynatt and Weber (1994) stated that, if mutually coherent visual and non-visual interfaces are available, collaboration is thus ensured. Petrie et al. (1995) argue that using a multi-modal display to represent spatial arrangements through tactile and auditory information would enable successful collaboration. Savidis et al. (1996) remark concerning the design of non-visual interfaces which parallel the display relationships of visual ones: "this will inherently lead to equal computer access opportunities for blind users".

On this view, both individuals with and without impairments are considered to have similar mental models. Thus, it seems reasonable to evaluate designs in terms of their effectiveness in enabling blind individuals to make analogous judgments and perform equivalent actions as their sighted counterparts (albeit with different technical resources). Such evaluations can be performed using classical individual testing methods.

From a different perspective, Hutchins (1995) not only emphasizes the emergent properties of socially distributed cognition, but also highlights how the properties of different representational media influence what can be represented and communicated using them. These studies bring some skepticism over the claims that collaboration between individuals with and without impairments is ensured as an inherent benefit of the cross-media translation of interfaces.

5 HUMAN INFORMATION PROCESSING MODELS

This chapter presents the MHP (CARD, 2017), a theory that aims to analyze humans as information processors, establishing an analogy between humans and computers. A relation between MHP and collaboration components is also provided to serve as a pillar of our method.

HCI is a multidisciplinary field related to the design and implementation of interactive computing systems (MATHEW; HAJJ; ABRI, 2011). Even though HCI has an experimental bias, theories have been developed in the field since its early years. These theories are mainly based on psychology, ethnography, and semiotics (BARBOSA; SILVA, 2010). Some of these theories advocate the interaction between humans and computers as a set of information processing tasks (PROCTOR; VI, 2012) and tend to analyze humans as information processors, establishing an analogy with computers. This is the case of the Human Processor Model, also known as MHP.

5.1 Human Information Processing Models

A well known version of MHP was developed by Card et al. (2017). It summarizes the psychology research to the date it was proposed in an engineering model. Such model establishes an analogy between the way humans perceive, remember, and act, and the way a computer works. It has been widely used to predict and study the human limitations and performance when interacting with computers (CRYSTAL; ELLINGTON, 2004; LIU; FEYEN; TSIMHONI, 2006).

The MHP sees humans as systems comprised by different types of processors, memories, and other resources. An important complement to this model was the inclusion of an attention component (CHRISTOPHER, 1984) - a limited resource representing the capacity that all processors share to pay attention to an information or a process. Figure 6 illustrates the MHP components and Figure 7 illustrates the information processing process with the addition of the attention resource.

MHP has three processor components: perceptual, cognitive, and motor. These

Figure 6: MHP components taxonomy (Source: author)

are respectively responsible for:

- (i) perceiving internal and external stimuli;
- (ii) processing, storing and retrieving information; executing complex processes such as comparisons, reasoning and taking decisions;
- (iii) coordinating muscles to act on the external environment.

MHP also has three memory components: sensorial, long-term, and working. As there is no consensus regarding the modality of such memory components (BADDELEY, 1992), it is not clear whether these are different systems or only represent different levels of information processing inside the same system. In addition, it comprises other resources such as a shared attention resource, sensors to gather information, and muscles to act on the external environment.

Any input from sensors is first stored in the sensorial memory, a relatively automatic and capacity limited frame buffer for stimuli received through the human senses (Figure 7). There are three main types of sensorial memory: iconic (visual), echoic (auditory), and haptic (tactile). Each of them has a particular decay speed, in which information is

Figure 7: Components of MHP with an attention resource (Source: author)

lost. If the information is not stored during this time, it is lost.

The information stored in the sensory memory that receives attention are processed by the perceptual processor, which uses information from the long-term memory to recognize symbols in it: letters, syllables, words, phonemes, icons, among others. This processor codes information in cycles of about 100ms each (PIROLI, 2007) and the coded information is then stored in the working memory (Figure 7).

Most adults can store between 5 to 9 items in their working memory, which is known by the magic number 7 (+2) (MILLER, 1956). However, the amount of information about each item that can be stored has not been explored. The decay time of information in the working memory is less than one minute (BADDELEY, 1990).

The cognitive processor takes the symbols identified by the perceptual processor and performs more complex processes, such as comparisons, reasoning, and deci-

sions. During these processes, it uses the long-term memory and can also store new symbols in the working memory (Figure 7).

According to the Atkinson—Shiffrin memory model (IZAWA, 1999), when information is being attended to in the working memory, it is automatically transferred to the long-term memory. The latter is thought to be unlimited and the information is stored in it by association.

When it is necessary to act on the external environment, the cognitive processor activates the motor processor, which instructs the muscles to execute it. There is an implicit loop feedback here in which the sensors gather information from this action and follow the same processes mentioned above to make any corrections.

Some studies based on the MHP have been criticized for being grounded on the idea of an average user (PROCTOR; VI, 2012), a tricky and not straightforward concept. We agree that people are different and, mainly when one considers people with impairments, the idea of an average user is vague. Nonetheless, if MHP is used to identify possible challenges that may arise in collaborative tasks due to impairments, it would be independent of the idea of an average user. Considering that, we do not use MHP to calculate lower and upper performance bounds. We use it to identify potential challenges during collaborative activities and to recommend ways to explore alternative solutions.

5.2 Dependencies between collaboration social mechanisms and MHP components

In this section, we return to the collaboration mechanisms mentioned in chapter 3 in order to establish some dependencies between them and MHP components.

Conversational mechanisms comprehend three components: a message, a channel, and a common code; and two entities: a sender and a receiver, as shown in Figure 8. Many researchers studied the communication process in terms of its relation to processing components (DYKE, 2012; MAHLER, 2014).

All processing components are important for communication (MAHLER, 2014). In order to produce a valid message, the senders' cognitive processor must be able to:

Figure 8: A representation of communication components (Source: author)

- (i) retrieve information from the long-term memory - the message content, code, and its rules -, a process that involve using the working memory;
- (ii) organize the content and properly encode it;
- (iii) send orders to the motor processor so that it coordinates the muscles related to the communication channel.

Analogously, in order to understand a message received, the receiver's perceptual processor must be able to access the sensory memory, retrieve information from the long-term memory (previous knowledge, the code and its rules), decode it, and send it to the cognitive processor. Subsequently, the receiver's cognitive processor must be able to organize and store the information at least during the time it will be required to perform the activity. The working memory is used in this process.

All MHP components play an important role in coordination. First, in order to understand a set of coordination rules, an individual must follow the process of receiving a message. The message received must be properly stored in the long term memory, which will naturally happens if the individual pays attention to the rules temporarily stored in the working memory. Considering the rules are available, the coordination process comprehends communication cycles that strongly use the cognitive processor. Each information received by the individual must be used to create a scenario. As an example, during a lecture, when an educator looks at a learner and makes her a question, it must be perceived as an indicator that the learner must answer the question in sequence. In order to do that, in addition to the communication process, an individual must constantly use its cognitive processor to verify if the scenario corresponds to a set of rules. In the presented example, the results of such processing may result in an activation of the motor processor and the muscles to answer the question or to stop answering if an interruption happens.

The cooperation process depends on the type of activity being conducted. It can require: fine motor skills, such as for threading a needle; fast sensory response, as for playing a game; great memory capacity, as for remembering large lists of commands and instructions; great cognitive processing capacity, as for understanding a model and editing it. Consequently, the dependence among the cooperation process and the MHP components also varies.

In order to process awareness information, in addition to what it was presented to the communication process, the participant's cognitive processor must be able to: (i) retrieve information from the long-term memory - the activity steps and the different states in which the object or artifact may be and what the associated meaning is - a process that involves using the working memory; (ii) relate the information gathered about the activity state with the work being done and react properly.

6 GRAPHICAL MODELS AND THE COMPUTING FIELD

This chapter discusses what are graphical models and how they are used in the computing field. This discussion is required in order to understand the context of the application we used to validate the method we propose, presented latter in this thesis.

6.1 Graphical Models

Hereon, we use the term *graphical model* to refer to models that use graphical representations to convey information. Due to its graphical nature, a single element in such models can convey various information through colors, shape, position, border thickness, and so on.

6.1.1 Graphical Models Classification

In this subsection, a classification of graphical models is presented. We use it later to identify what types of graphical models are used in the computing field.

We abstracted some of the characteristics present in the classifications of graphical representations found in the literature (KING; EVANS, 2007) and, based on this abstraction, we propose a classification of graphical representations according to the following criteria:

- (i) dimensionality;
- (ii) dynamicity;
- (iii) spatiality; and
- (iv) language.

Dimensionality refers to the number of dimensions used in the representation. There are two main alternatives considering dimensionality: two dimensional (2D) and three dimensional (3D). A flat world map is an example of a 2D model (Figure 9a).

Figure 9: Examples of graphical representations with different dimensionalities: (a) two-dimensional map (Source: Pexels) (b) photo of a three-dimensional map (Source: Pexels)

(a)

(b)

When relief details are present, such as in a land relief map, it is a 3D representation (Figure 9b).

With respect to dynamicity, a representation can be static, if it does not change with time, or dynamic, if it changes. In this criterion, time is not considered as one of the axes of representation, but a reference in relation to which the representation can change. In this way, an *Entity-Relationship Model* (ERD) (CHEN, 1982) is an example of static representation. The set of variations in the cloud positions is an example of a dynamic representation.

Spatiality is related to the relative position of elements within a diagram. Whenever the representations in which the relative position of the elements in a diagram transmit important information for understanding its content, it is categorized as spatial. Those in which the positioning does not transmit important information are categorized as non-spatial. The UML sequence and class diagrams may be considered examples of spatial (Figure 10) and non-spatial (Figure 11) representations, respectively. In a sequence diagram, the time depends on the position of a message (horizontal line segment with an arrow) on the vertical axis. For instance, the message `searchByNumber` in Figure 10 happens after the message `searchById`. The meaning of a class diagram, in turn, does not change even if the position of any element is changed.

In relation to language, some representations have its content specified by a vo-

Figure 10: Example of spatial graphical representations: the UML sequence diagram
(Source: author)

Figure 11: Example of non-spatial graphical representations: the UML class diagram
(Source: author)

cabulary and syntactic rules. In other representations, no graphical language is used. Examples of representations with languages are the diagrams of the computing field (Figure 10). Representations without language include photos and illustrations of some scene (Figure 12). These two types of representations are categorized by King and Evans (2007) as diagrammatic and pictorial, respectively.

Figure 12: Example of representation that do not follow any language (Source: Pixabay)

Two-dimensional, static, and language-based representations are commonly known as diagrams. These representations use less visual information than three-dimensional, dynamic, spatial, and non-language-based representations. In this way, it is harder to transform the latter into stimuli for the other senses (hearing and touch, for example).

6.2 Graphical Models in Computing

Graphical models are frequently used in the computing field. These models are often represented in the form of nodes and edges, but have specificities that result in complex graphical notation. Examples of this complexity include the class diagram of UML and ERD, in which the inherent complexity of a node is often greater than that

resulting from its connections, an unusual property for graphs.

With very few exceptions, these models can be categorized as two-dimensional, static, non-spatial, and language-based. Exceptions include, for instance, *Business Process Model and Notation* (BPMN) models and UML activity diagrams, in which the positioning of elements in processes, partitions, or swimming lanes transmits important information. These are examples of spatial models. Table 1 presents some computing areas and the most common used graphical models.

Table 1: Examples of graphical models usage when considering some computing areas

	BPMN	DFD	ERD	Flowchart	Graph	IDEF	MHD	MSD	Petri Nets	UML	SysML
Algorithms and Data Structures				✓	✓						
Analysis of Algorithms					✓						
Artificial Intelligence					✓						
Automata and Computability					✓						
Compilers					✓						
Database			✓								
Distributed Systems									✓		
Formal Languages					✓						
Graph Theory					✓						
Performance Analysis					✓						
Programming Language				✓							
Software Engineering	✓	✓				✓	✓	✓		✓	✓

6.3 UML - Unified Modeling Language

UML is a standard notation for the development of object-oriented software. It was created in the mid-1990s from an effort to unify some object-oriented modeling techniques (RUMBAUGH; JACOBSON; BOOCH, 2004), notably Booch (1994), *Object Modeling Technique* (OMT) (RUMBAUGH et al., 1991) and *Object Oriented Software Engineering* (OOSE) (JACOBSON, 1993). It is not a development method, but a language that specifies models and diagrams to represent different aspects of software systems, from business to deployment.

Currently in version 2.5.1, the language has 14 types of diagrams, organized into two large groups: structural and behavioral. The first group involves diagrams that represent the system from a static point of view, including diagrams of: classes, compo-

nents, objects, profile, installation (or deployment), package and composite structure. The second group, in turn, includes a set of diagrams to represent dynamic aspects of a system, including its execution. The diagrams in this group are: use cases, state, activities, sequences, interaction overview, collaboration and time.

In the scenario that motivated this research, we consider collaborative activities involving one type of UML diagram: the use case diagram.

Use-case diagrams specify the functionalities of a system from the point of view of external entities (such as people, organizations, and other systems). External entities, known as actors, are represented by stick figures. The system's functionalities, called use-cases, are represented by ellipses. As an example, we present in Figure 13 a use case diagram of a library loan management system. In this diagram, there are three (3) actors: User, Client and Librarian. Also, there are five (5) use cases: Book Billing, Account Management, Manage Collections, Manage Loans, and Authenticate User. The actors and use cases are related through associations (full lines) and indicate the role that an external entity assumes when interacting with a system use case.

Figure 13: A use case diagram for a library loan management system (Source: author).

6.3.1 Challenges to Learners with Visual Impairment

Educators use graphical representations to teach and to exemplify concepts (OWEN; COBURN; CASTOR, 2014), and learners with visual impairment are sometimes not allowed to express their knowledge through alternative tasks (MÜLLER, 2012). In order to convey information in graphical representations to learners with visually impaired in classroom activities, educators would have to receive support from assistants or use low/high-tech assistive technologies (DELL; NEWTON; PETROFF, 2016). Examples of low-tech assistive technologies are tools such as pens or tactile drawings (LOITSCH; WEBER, 2012), and physical objects with specific semantics (BROOKSHIRE, 2006; MCMULLEN; FITZPATRICK, 2009). Examples of high-tech assistive technologies are tactile displays (GILKES; COWENS; TAYLOR, 1996), *Optical Character Recognition* (OCR) (CHARLES et al., 2012), screen readers (BORODIN et al., 2010), among others.

In addition to the accessibility of graphical content, the accessibility of software systems used in computing education programs, such as *Integrated Development Environment* (IDE) and *Computer-Aided Software Engineering* (CASE), is also important to make inclusion possible.

More information about the challenges to include learners with visual impairment in computing education programs may be found in Appendix C.

PART III

RESEARCH DEVELOPMENT AND RESULTS

Part Overview

This part of the thesis presents the results achieved while conducting this research. It begins with chapter 7 and the description of evidences that assure the relevance of the problem we are addressing and the originality of its solution. These evidences guided us to develop and test a groupware as a technological solution for including individuals with visual impairment in online collaborative modeling activities. This is described in chapters 8 and 9. Having developed and tested an inclusive groupware that fulfilled all the inclusion requirements from the literature, user tests showed diversely of what was advocated by others (MYNATT; WEBER, 1994; PETRIE; MORLEY; WEBER, 1995; SAVIDIS et al., 1996), since collaboration was not ensured. New evidences brought us the need for a method to support inclusive groupware design (or redesign). Collab4All was proposed with that aim, and it is presented in chapter 10. As a proof of concept for Collab4All, we apply it to redesign and test Model2gether, the inclusive groupware previously developed. The proof of concept is provided in chapter 11, closing this part of the document.

7 EVIDENCES FROM THE LITERATURE REVIEW, TOOL SEARCH AND SURVEY WITH QUESTIONNAIRES

This chapter describes part of the results of the first DSR iteration conducted during this research. In order not to make it extensive, marginal information regarding the results were left to be presented in appendices.

7.1 Literature review

In order to assure the broadness and relevance of the challenge we were addressing - promoting inclusion of individuals with blindness in collaborative modeling activities -, we conducted traditional literature reviews.

Having read the selected papers, we noticed that the challenge we faced has been faced by many others. In terms of broadness and relevance, we have found studies in Australia (WHITBURN, 2014), Brazil (ALVES et al., 2009; GRILLO; FORTES, 2014a; GRILLO; FORTES; LUCRÉDIO, 2012; PANSANATO; SILVA; RODRIGUES, 2012; SILVA; PANSANATO; FABRI, 2010), Canada (FICHTEN et al., 2009; SMITH; KELLEY, 2007), South Africa (FRASER; MAGUVHE, 2008), UK (DOUGLAS, 2001), and the USA (ABNER; LAHM, 2002; BROOKSHIRE, 2006; EDWARDS; LEWIS, 1998; KAPPERMAN; STICKEN; HEINZE, 2002; SMITH; KELLEY, 2007), to cite just a few. Some of the papers have shown that educators lack training and are not well prepared to teach learners with visual impairment (ABNER; LAHM, 2002; EDWARDS; LEWIS, 1998; KAPPERMAN; STICKEN; HEINZE, 2002).

When considering only the inclusion in computing diagram-based courses, to cite just a few, we have found papers that covered *Data Flow Diagram* (DFD) (BLENKHORN; EVANS, 1998), graphs and data structure (CALDER et al., 2006; COHEN et al., 2005; COHEN; MEACHAM; SKAFF, 2006; COHEN et al., 2006), the UML diagrams (BROOKSHIRE, 2006; FÖDISCH; CROMBIE; IOANNIDIS, 2002; GRILLO; FORTES, 2014a; GRILLO; FORTES; LUCRÉDIO, 2012; HORSTMANN et al., 2004; KING et al., 2004; KING; EVANS, 2007; LOITSCH; WEBER, 2012; METATLA et al., 2012a; MÜLLER, 2012; SILVA; PANSANATO; FABRI, 2010; OWEN; COBURN;

CASTOR, 2014; PANSANATO; SILVA; RODRIGUES, 2012; PETRIE et al., 2002), and general graph-based diagrams (BALIK et al., 2014; BROWN; STEVENS; PETTIFER, 2004; FITZPATRICK; MCMULLEN, 2008; KENNEL, 1996; RAMLOLL; BREWSTER, 2002b). Most of them are related to providing accessibility for individuals with blindness while interacting with such diagrams. For the ones that address including individual with blindness in collaborative activities involving modeling and editing diagrams, none of them addressed inclusion considering all collaboration components and real time collaboration.

Appendix B presents further details of the literature review performed.

7.2 Tools Review

Through literature review, we realized that the use of textual notations was a common solution to make UML diagrams more accessible to individuals with visual impairment. In order to search for tools that use this strategy, we visited the 100 sites considered the most relevant by the search engine Google when searching for ("UML from text" OR "textual UML" OR "UML textual" OR "UML em texto").

As result, 26 of the 100 most relevant sites had references to tools. A total of 20 different web-based and desktop tools were found. Table 2 presents the tools found in the first search, their associate platform, and the UML diagrams they implement. A more recent version of the tools list may be found in Luque et al. (2015a).

In order to assess the accessibility of each tool, we followed two different paths. For desktop tools, we assessed them simulating a usage scenario using two different screen readers: JAWS (2018) and *NonVisual Desktop Access* (NVDA) (2018). For web-based tools, we discarded AWMo because its accessibility had already been tested and published in the literature (GRILLO; FORTES, 2014b). Then, we checked each of the 10 remaining tools regarding its conformance to WCAG 2 and conducted a usability test. Concerning conformity to WCAG 2, we used a free service (ACHECKER, 2018) and registered every identified problem. This service evaluates the source code of single web pages and produces a report with the identified problems in each WCAG 2 level: A (The lowest conformance level), AA, and AAA (The highest conformance level). The report produced by this service includes the requirements that were not

Table 2: List of UML textual tools and the diagrams they implement

[illegible]

fulfilled, a description of each error found, the code line and column where each error was found, and suggestions for correction. Furthermore, this service indicates potential problems that require human verification. The conformance to WCAG 2 is the minimum expected software requirement for web-based tools that wants to include people with impairments.

None of the desktop tools were fully accessible to individuals with blindness because they lack proper keyboard navigation and alternative texts. When considering the web-based tools conformity to WCAG 2, all tools except for *Accessible Web Modeler* (AWMo) were not in full conformance, since they presented at least one type of Level A problem - the minimum level of conformance. The non-conformity problems that can affect users with blindness were related to language definition, image description, and form field labeling. The first problem influences the way assistive technologies and user agents render web-page contexts. For instance, if a language is not specified, which was the case of many tools, screen readers may not load correct pronunciation rules, visual browsers may not correctly display characters and scripts, and media players may not properly show captions (W3C, 2008). The second problem does not allow people with blindness to recognize images content since they do not have an associate textual description. Finally, the third problem may impose difficulties when users interact with form fields. Without an appropriate description, the content that must be informed in a field may not be understood.

In addition to the identified problems, many potential problems were also identified. These problems are mainly related to semantics and cannot be evaluated by a tool. In this sense, the usability tests results are complementary to the conformity evaluation ones. In Table 3, we present a summary of non-conformity problems and of the number of problem occurrences per different HTML elements, as well as the number of potential problems for each tool. We considered only problems that may affect users with blindness when interacting with these tools.

After assessing tools conformance to WCAG 2, we conducted usability tests. Due to the large number of UML tools we had found to date, we split the tests into two phases (with 5 tools each) to reduce participants' workload. Tools selection for each phase was made by using a pseudo-random number generator (WICHMANN; HILL, 1982). The first phase involved testing Diagrammr (not available anymore), js-

Table 3: A summary of what was found in the WCAG 2 conformance evaluation.

Tool	Language Not Defined	Missing Label	Missing Textual Description for Image	Potential Problems
Diagrammr	-	1	-	95
js-sequence-diagrams	1	20	-	142
MetaUML	1	4	1	90
PlantTextUML Editor	1	1	-	88
PlantUML	1	2	-	103
SeedUML	1	19	32	218
Seqdiag	1	1	-	101
Umple	-	25	10	99
WebSequenceDiagrams	1	5	8	169
yUML	-	-	-	-

sequencediagram (JS-SEQUENCE-DIAGRAMS, 2018), Seqdiag (SEQDIAG, 2018), WebSequenceDiagrams (2018), and yUML (2018). The second phase involved testing MetaUML (METAUML, 2018), PlantTextUML Editor (PLANTTEXTUML, 2018), PlantUML (2018), SeedUML (2018), and Umple (UMPLE, 2018). The tests were performed remotely with the aid of the research author, available for answering any question. Details about the test preparation are provided in appendix D.

During the first phase of usability tests, participants had experienced accessibility problems with js-sequencediagram and Seqdiag. Moreover, they were able to access, navigate, create and export the diagrams specified in the instructions for Diagrammr, WebSequenceDiagrams, and yUML. During the second phase, participants faced barriers accessing MetaUML and SeedUML. Regarding PlantTextUML Editor, PlantUML and Umple, as for the first phase, participants were able to access, navigate, create and export the diagrams specified in the instructions.

Although the results of the tests with users indicate that most of the evaluated tools may be used following specific instructions, even not presenting conformance to WCAG 2. In addition, there were still remaining gaps related to the inclusion of people with blindness in some UML-related learning activities and in the software development industry. Despite all evaluated web-based textual UML tools implement the basic features of model creation and editing for people with blindness, not all of them support direct model saving and loading (AWMo, js-sequence-diagrams, MetaUML, SeedUML and Seqdiag). In these tools, to save and load a diagram, its textual description must be copied to a text editor, then saved as a text file and pasted in the tool to generate the diagram again. Moreover, when considering the interaction with sighted people, there is a gap related to the visual representation of some tools (Diagrammr, js-sequence-diagrams and Umple), which are not exactly in accordance with the UML default notation. Additionally, another gap concerns the diagrams implemented by existing textual tools. Despite they support the most used diagrams (DOBING; PARSONS, 2006), five (composite structure, deployment, interaction overview, profile and timing) of the fourteen UML 2.5.1 diagram types are not implemented. Especially in computing-related courses, where students must deeply study the language, this is an important issue to be taken into account. With respect to collaboration, the only tool that implements it at some level is AWMo. However, real-time interaction is not supported. Finally, the

evaluated tools lack interaction with existing UML CASE tools. This may impose difficulties for their adoption in industry, since projects are driven by tight schedules and productive UML CASE tools are adopted by sighted people.

7.3 Survey with questionnaires

We also conducted a survey using questionnaires aimed at identifying the practice and perceptions of educators and learners with visual impairment regarding their inclusion in computing education programs. Particularly, we aimed at gathering information about the following aspects:

- Institutional provision for educators and learners;
- Changes in didactic methods (lecture style, accessibility of graphical representations, assessment, and group activities);
- Perception of changes in didactic methods.

The research was carried out by sending electronic questionnaires, with multiple choice and short answer questions, targeting two distinct groups: (i) educators in the field who have taught learners with visual impairment; and (ii) learners with visual impairment who have attended courses in the field. The questionnaire for educators was created using Google Docs forms (DOCS, 2015), and SurveyMonkey (2018a) was used for learners considering the lack of accessibility of the former to individuals with visual impairment (BUZZI et al., 2010). SurveyMonkey advertises its compliance with Section 508 (MUELLER, 2008) and WCAG 2 (W3C, 2008). In addition, other studies in the literature used SurveyMonkey to apply questionnaires to individuals with visual impairment (WENTZ; LAZAR, 2009; WENTZ; HOCHHEISER; LAZAR, 2013). The questionnaires were released to receive responses from June 12 to October 16, 2015. The responses were analyzed through descriptive statistics - generation of contingency tables and calculation of percentages. The appendix C presents the results of such survey.

The survey with questionnaires received 56 responses from educators that have had experience of teaching computer science subjects to visually impaired learners.

Moreover, there were 31 respondents to the visually impaired learners questionnaire, of whom 19 were considered valid. We considered invalid those responses that were incomplete and contained only information about the learner's visual impairment degree. The respondents include 7 learners that were currently attending a computing education program, corresponding to 37% of all respondents, and 12 learners that previously attended a program in the field, corresponding to 63%. From those that have already attended a program in the field, only one did not complete the program. Regarding their degree of visual impairment, 16 learners (84%) declared to be completely blind and 3 (16%) as having low vision.

The results indicated that, despite any effort by educators and institutions to promote a more inclusive scenario, most learners do not feel included at all. The appendix C presents details about the results, including suggestions to promote a more inclusive scenario in Brazil.

Considerations

In this chapter we described the results from the first activity of the adopted DSR method. They bring evidences that including individuals with blindness in educational settings is still an important problem to be addressed. Moreover, although several attention has been devoted to include individuals with blindness in individual activities, there are still room to improve it in collaborative activities.

All these evidences served as basis for the decision of building a groupware to support inclusion of individuals with blindness in UML modeling activities, which is described in the next chapter. The results presented in this chapter were reported in journals (LUQUE; BRANDÃO; BRANDÃO, 2018; LUQUE et al., 2018).

8 BUILDING A GROUPWARE BASED ON EVIDENCES

In this chapter, we describe Model2gether and its associate development process. Model2gether is a groupware we developed to support the inclusion of individuals with blindness in collaborative diagram-based activities. It is an artifact build as part of the DSR first iteration.

8.1 Overview of the development process

In order to develop Model2gether, we followed an iterative and incremental process based on *IBM Rational Unified Process* (IRUP) - a software process framework that provides a set of industry-tested practices for software development, maintenance, and acquisition (SHUJA; KREBS, 2007). We cannot affirm that we fully adopted IRUP because we did not follow the framework activities and tasks strictly. We also did not customize it - one of its key principles: "Adapt the process". Nevertheless, we followed the general structure of IRUP disciplines and created some IRUP artifacts: Software Requirements Specification and Software Architecture Document.

Although an iteration plan was not created, the following iterations were conducted for each of the IRUP phases:

- A single iteration in the inception phase to establish the scope, vision and some project requirements. Low-fidelity prototypes were also created;
- A single iteration in the elaboration phase for refining requirements, artifacts already produced, and for proposing a candidate architecture. A first implementation of the candidate architecture was done.
- Three iterations in the construction phase, in which the main focus were implement requirements and refine the architecture;
- A single transition iteration for finishing implementation, conducting final tests and for product deployment.

8.2 Establishing the groupware requirements

In order to define requirements for Model2gether, we initially explored the problem space and analyzed how interaction could be established between users (aka participants) - instructors and learners - and content during the teaching and learning process. This can be understood as a *business modeling* activity.

This analysis was based on the author's experience in teaching object orientation with UML, which led us to consider four activities as common ones during the process:

- (i) Presentation of diagrams and explanation of their structure/content;
- (ii) Step-by-step construction of diagrams, individually or collaboratively;
- (iii) Presentation of diagrams and questioning about problems in their structure/content;
- (iv) Peer reviews and evaluation of diagrams created by third parties;

In order to support these four activities, we began the specification of Model2gether requirements by defining stakeholders' intentions (ISO, 2011a), sometimes known as user requirements (WIEGERS; BEATTY, 2013). Based on Mynatt and Weber (1994), who stated that if mutually coherent visual and non-visual interfaces are available collaboration was ensured, we decided to develop an accessible version of the sighted user interface to participants with blindness. Therefore, Model2gether had to guarantee that a diagram could be created, accessed and edited by all participants. We implemented only two collaboration-related intentions: (i) the possibility of "pointing to" a diagram element; and (ii) a continuous awareness of what others are doing. These are required to conduct presentations. Verbal communication was supposed to be done using other solutions, such as any VoIP service. Next, we present the stakeholders' intentions we defined, as well as some requirements gathered from the literature (LUQUE et al., 2014; LUQUE et al., 2015a).

- When considering participant-groupware intentions:
 - Open an existing diagram;

- Create new diagrams;
- Access diagrams in an accessible format;
- Edit diagrams in an accessible format;
- Share diagrams with others;
- When considering participant-groupware-participant intentions:
 - Simulate "pointing to" a diagram element to complement verbal communication;
 - Be aware of what diagram elements other participants are creating/editing;
 - Be aware of what diagram elements other participants are "pointing to" in order to complement verbal communication;

Table 4 presents the relation between these intentions and the four activities we considered as common ones during the collaboration.

Table 4: Relation between stakeholders' intentions and domain activities

Stakeholders' Intentions	i	ii	iii	iv
Open an existing diagram	✓		✓	✓
Create new diagrams	✓	✓	✓	
Access diagrams in accessible formats	✓	✓	✓	✓
Edit diagrams in accessible formats	✓	✓	✓	
Share diagrams with others	✓	✓	✓	✓
Simulate "pointing to" a diagram element to complement verbal communication	✓	✓	✓	
Be aware of what diagram elements other participants are creating/editing	✓	✓	✓	
Be aware of what diagram elements other participants are "pointing to" in order to complement verbal communication	✓	✓	✓	

Based on these intentions, we defined user stories from the perspective of sighted participants, participants with blindness, and general - without distinguishing these two groups. User stories related to the way participants comment on diagrams in evaluation or review activities was not considered. This decision is due to the fact that it is generally accomplished by text, a cross-accessible format for both sighted participants and participants with blindness. These user stories are shown in Table 5.

Table 5: Model2gether requirements specified as user stories.

As a participant, I want to	(1) point to elements of diagrams I am editing, so that others can follow what I am explaining
	(2) access a history of changes made to a diagram element by other participants, so that I can understand and trace how the element came to its current status
As a sighted participant, I want to	(3) create and edit diagrams using a graphical notation, so that I can specify and document functional requirements
	(4) have access to diagrams created by other participants using a graphical notation, so that I can understand and contribute
	(5) follow 'pointing to' and changes made by other participants during activities and navigate throughout the pointed elements using a graphical notation, so that I am able to follow an explanation and collaborate
As a participant with blindness, I want to	(6) create and edit diagrams using a textual description, so that I can specify and document functional requirements
	(7) have access to diagrams created by other participants using a textual description, so that I can understand and contribute
	(8) follow 'pointing to' and changes made by other participants during activities and navigate throughout the pointed elements using a textual description, so that I am able to follow an explanation and collaborate

Some of these user stories have different purposes for instructors and learners. Table 6 describes their purposes according to the reasons for being relevant to each one.

Table 6: Usage purpose of some requirements.

User Story	Instructor	Learner
3, 6	Prepare presentations and delivery content to learners	Elaborate assignments and exams
4, 7	Evaluate assignments and exams	Access course materials and make peer reviews

Regardless of referring to only individuals with blindness, these user stories are valid for including other people with any degree of visual impairment.

In order to define a diagrammatic view of such user stories, we organized them in use cases. During the development process, these use cases were detailed using narrative descriptions of scenarios. Figure 14 presents the final use case diagram for Model2gether and Table 7 presents an example of description for a use case scenario.

Figure 14: Model2gether use case diagram (Source: author).

Table 7: An example of description for a Model2gether use case scenario

Identification:	UC01
Type:	Primary and concrete
Actors:	Participant
Name:	Create Diagram
Short description:	This use case allows participants to create new use case diagrams
Pre-conditions:	The participant must have been previously authenticated by the system and the authentication must still be valid
Main flow:	<p>M1 - The participant selects the option 'Create Diagram';</p> <p>M2 - The system shows a form and asks for the following diagram-related data: type (only use case for the moment), name, and description;</p> <p>M3 - The participant informs the required information and confirm;</p> <p>M4 - The system saves the new diagram.</p>
Alternative flows:	None.
Exception flows:	<p>E1 - This exception flow may happen after M3: when the participant does not inform the required data (type and name).</p> <p>E1.1 - The system show an error message and highlights the fields that must be filled in order to create a new diagram.</p> <p>E.1.2 - The flow returns to M3.</p>
Post-conditions:	A new diagram has been created and saved.

We also defined non-functional user requirements for Model2gether. Next, we present these requirements organized by their category:

- Usability:
 - The system must be easy to install and access, requiring few or none configuration;
 - The system must be accessible to individuals with blindness.
- Portability:
 - The system must not depend on specific platforms.
- Reliability/Security:
 - The user sensitive information must be secured.
- Supportability:
 - The system must be easy to maintain.

These non-function user requirements were further detailed later. The derived non-functional software requirements are described next.

- NF01: The system must be implemented as a web-based solution;
- NF02: The system must conform to E-MAG and WCAG guidelines;
- NF03: The system must implement the 10 Nielsen heuristics (NIELSEN; MOLICH, 1990);
- NF04: The system must be modular and object-oriented;
- NF05: The user password must be stored encrypted with BCrypt (PROVOS; MAZIERES, 1999).

8.2.1 Software Architecture

In software development projects, one of the first design-related decision concerns whether create it as an extension of an existing tool or as an independent solution. For this case, the decision was between creating an add-on to a UML CASE tool or an independent solution. The development of thirty-party add-ons can be difficult as it involves new code integration, which is limited by the existing code and structure. Also, some collaboration-related requirements may not be implemented in some tools as they require functionality of being listeners of selection events (e.g. when a user clicks on a diagram element). Considering this and the fact that portability is a non-functional requirement, Model2gether was designed as an independent web-based solution.

In order to design Model2gether, we firstly identified the use cases and non-functional requirements that would have a bigger impact on architecture. The following use cases were identified: Edit Diagram, Notify Participant, and Point to Diagram element. These use cases require continuous synchronization between participants' diagram representation, so that when a participant makes changes to a diagram, others can be notified and their diagram representation updated. The same applies for pointing to a diagram element.

Moreover, the following non-functional requirements were identified as the most relevant for architecture definition: NF01 and NF04. These requirements impact the architecture since web-based and object-oriented systems have some peculiarities related to the underlying technologies (HTTP/HTTPS) and paradigm (classes, objects, inheritance, polymorphism etc.), respectively.

Considering that, we organized Model2gether in 4 logical modules, as shown in Figure 15. The Domain Module contains classes that implement domain abstractions, such as User and Sharing. Additionally, it contains a domain model that can represent graph-based (with graphs nested in nodes) diagrams. Figure 16 presents the domain model as a UML class diagram.

The web-independent services are located in the Business Service Module. In addition to other services, it manages the persistence of classes in the domain module. Additionally, it contains classes responsible for producing changes in the meta-model

Figure 15: Model2gether architecture representation (Source: author).

and for managing the set of rules that must be followed to produce a valid diagram instance.

The Web Service Module is responsible for using web-based protocols to keep diagram representations synchronized. It also supports managing security-related concerns, and controlling the application flow.

Finally, the Presentation Module is responsible for presenting diagrams to and controlling interactions with participants. It has a copy of the meta-model that must be kept synchronized with the server-side.

8.3 Implementing the solution

The main decisions concerning technology were: (i) adopting an existing framework to leverage the development effort and to profit from the tested components; (ii) using design patterns (GAMMA et al., 1995) for providing synchronization during collaborative activities; and (iii) using a *Domain Specific Language* (DSL) (FOWLER;

Figure 16: Model2gether domain model (Source: author).

PARSONS, 2010) to provide textual description of UML diagrams.

The Domain Module classes were implemented as *Plain Old Java Objects* (POJO)¹. In order to implement synchronization, all domain model elements implement the *Observer* design pattern (GAMMA et al., 1995). By doing so, any change made to the domain model is immediately notified to its observers.

In the Business Service Module persistence was implemented through the *Data Access Object (DAO)* design pattern and a *Java Persistence API (JPA)*-based implementation. In order to manage the set of rules that must be followed to produce a valid diagram instance, we used the *Factory* and *Strategy* design patterns. All services in this module are accessible through a *Facade*, another design pattern, that simplifies its usage.

The Web Service Module was implemented through *Spring MVC*² controllers and

¹ <https://www.martinfowler.com/bliki/POJO.html>

² <https://docs.spring.io/spring/docs/current/spring-framework-reference/web.html>

view-models. Excluding the sign in, sign up, and error pages, all other resources are filtered through an intercepting filter.

The Presentation module was written using *JavaServer Pages (JSP)*, *HTML 5*, *CSS 3*, and *Javascript*. In this module, a *Javascript* instance of the meta-model is used to represent the model being edited. One of the domain model observers is a *Javascript* controller that sends messages to the Web Service Module through a no-polling strategy ³. Currently, the tool uses the *JSUML2* library⁴ to draw use case diagrams.

From a deployment perspective, the implementation was monolithic and Model2gether runs in a single server instance.

8.3.1 Interfaces

Model2gether implements two different interfaces: a screen-reader compatible interface for blind users (Figure 17) and a graphical interface for sighted users (Figure 18). In the former, models are specified through a DSL. The elements that may be modeled through the DSL are: actors, use cases, associations, dependencies (inclusion and extension), as well as actor and use case inheritance. Interaction is possible through shortcuts - a combination of modifiers and keys (e.g. Ctrl+Shift+A) - and keyboard navigation.

The interface for sighted users shows use case models in their diagrammatic format and interaction is possible through mouse and keyboard. A model may be shared with other participants through a sharing option, shown in the main screen. In addition, all use case models owned by the user or shared with him/her are shown (Figure 19). Finally, there are options for a user to manage his/her profile.

Model2gether's accessibility was checked regarding its conformance to WCAG 2. In order to do that, we used an automatic free service (ACHECKER, 2018). No problems were found by the service.

³No-polling is the strategy adopted by Google Docs developers - requests made to the server are kept opened and, as soon as new information arrives to the server, it is sent back to the client

⁴<https://code.google.com/archive/p/jsuml2/>

Figure 17: Model2gether interface for users with blindness (Source: author).

8.4 Comparison with Similar Tools

To date, there were two groups of tools with which Model2gether was related to. The ones that allow the specification of UML models through text (MetaUML, Plant-TextUML Editor, PlantUML, UMLetino, and yUML) and the ones that seek to support collaborative modeling involving people with blindness, as CCMi and AWMo.

A comparison of Model2gether with the ones listed above is provided in Table 8.

Figure 18: Model2gether interface for sighted users (Source: author).

Figure 19: Model2gether main menu (Source: author).

Name	Type	Shared	View as
Library System	Use Case Diagram (UML)	-	Text, Diagram
Furniture Store System	Use Case Diagram (UML)	-	Text, Diagram
Sales Management System	Use Case Diagram (UML)	-	Text, Diagram
Chat System	Use Case Diagram (UML)	-	Text, Diagram
Virtual Drive System	Use Case Diagram (UML)	OK!	Text, Diagram

The screenshot shows the 'Model2gether - User area' interface. The browser address bar shows 'model2gether.com/index.jsp?'. The navigation bar is identical to Figure 18. Below the navigation bar, there is a table titled 'Content'. The table has four columns: 'Name', 'Type', 'Shared', and 'View as'. The 'View as' column contains buttons for 'Text' and 'Diagram'. Each row represents a system, with a green icon to the left of the 'Name' column. The 'Virtual Drive System' row shows 'OK!' in the 'Shared' column, while the others show '-'. Each row also has an 'Edit Sharing' button.

Table 8: Tools comparison

Feature	collaborative Modeling			Textual UML Editors				
	Model2gether	CCMi	AWMo	MetaUML	PlantTextUML Editor	PlantUML	UMLetino	yUML
1. Allow textual editing	✓		✓	✓	✓	✓	✓	✓
2. Allow graphical editing	✓	✓	✓				✓	
3. Support model sharing	✓	✓	✓	✓	✓	✓	✓	✓
4. Support model storing	✓	✓		✓	✓	✓	✓	✓
5. Allow exporting to image	✓	✓			✓	✓	✓	✓
6. Support Real-Time (RT) cooperation	✓	✓						
7. Implements RT communication mechanisms	✓							
8. Implements RT awareness mechanisms	✓							
9. Implements RT coordination mechanisms		✓						

Considerations

In this chapter we described the development process of Model2gether, an inclusive groupware to support UML Use Case modeling involving sighted and blind individuals. Its requirements were established by considering that providing mutually coherent visual and non-visual interfaces would ensure collaboration. Model2gether was described and reported in two demo papers (LUQUE; BRANDÃO; BRANDÃO, 2016; LUQUE et al., 2016). The demo paper (LUQUE; BRANDÃO; BRANDÃO, 2016) was awarded as *Best Prototype* of Apps.edu@CBIE2016 (Brazilian Conference on Informatics and Education) and (LUQUE et al., 2016) was awarded with *Honored Mention* at the Tool Session of CBSOft 2016 (Brazilian Conference on Software). In the next chapter we will describe Model2gether evaluation through the execution of user tests.

9 EVALUATING THE SOLUTION WITH TARGET USERS

In order to deploy and evaluate the first version of Model2gether, we firstly assessed its conformance to WCAG 2, using the same tool we used earlier (ACHECKER, 2018). No problems were found. Having passed the conformance test with WCAG 2, we conducted user tests: two series of e-learning lectures on software requirements specification using UML use case models. Each series of lectures was attended by one participant with blindness and 4 sighted participants, totaling 10 participants in the two series. The next sections present details about these tests and analyze their results.

9.1 Participant Recruitment

Participation was voluntary. The individuals with blindness were invited through a blind programmers list (FORUM, 2018). The eight sighted individuals were invited through alumni lists of the authors' institutions.

Participants were asked to answer a questionnaire about their profile. The questions were about their:

- (i) age;
- (ii) gender;
- (iii) previous experience with screen readers (for participants with blindness);
- (iv) previous experience with the use case model and its related concepts;
- (v) blindness condition - since birth or acquired later (for participants with blindness);
- (vi) previous experience in computing or engineering courses.

Tables 9 and 10 shows the participants' profile. In them, NU means "never used".

Table 9: Participants' profile of the first lecture series

Participant	Age	Gender	Blindness	Previous Experience with Screen Readers (in years)	Used Screen Reader
#1	22	Male	Completely Blind	11	NVDA
#2	43	Male	Sighted	NU	NU
#3	24	Male	Sighted	NU	NU
#4	22	Male	Sighted	NU	NU
#5	20	Male	Sighted	NU	NU

Table 10: Participants' profile of the second lecture series

Participant	Age	Gender	Blindness	Previous Experience with Screen Readers (in years)	Used Screen Reader
#6	40	Male	Completely Blind	10	NVDA
#7	25	Male	Sighted	NU	NU
#8	21	Male	Sighted	NU	NU
#9	24	Female	Sighted	NU	NU
#10	23	Male	Sighted	NU	NU

9.2 Awareness for the learners with blindness

Continuous awareness was used while the instructor was teaching the content and while the learner with blindness was working with other learners in a group. Therefore, every time a user changed the model (visual changes, such as moving and resizing, are not reflected to people with blindness) or pointed to an element, the learner with blindness listened to beep and audio messages (e.g. "A new use case was created: Borrow Material"). The awareness audio messages was produced by Model2gether using *Text-to-Speech* (TTS) technology available in web browsers.

9.3 Preparation

In order to coordinate the lecture, we used a synchronous communication mechanism. However, to conceal the presence of sighted or participants with blindness, we used the communication mechanism without any video image. As aforementioned, before the lecture, participants were asked to answer a questionnaire about their profile. Additionally, they had to answer the following questions to assess their previous knowledge about the subject.

1. What are system requirements?
2. What is the difference between functional and non-functional system requirements?

3. What are actors in use case models?
4. What are use cases in use case models?
5. What are associations in use case models?
6. What are dependencies in use case models?
7. What are generalizations in use case models?

Their answers were assessed and they received a grade from 0 to 10.

To get familiar with the tool, we invited participants to conduct a preliminary use of it. For this, they were asked to carry out the following activities: (i) open the tool website and create an account; (ii) sign-in into the system; (iii) find the help menu, open and read it; (iv) open a use case model that was shared with them and read its content; and finally (v) make a change in the model.

9.4 Lecture dynamics

Before starting each series of lectures, the instructor gave an overview of what would be done. He explained that they would have lectures about requirements specification using UML use case models and, after that, they would work in groups of three learners in an activity. Each series was composed of 3 lectures of 40 minutes each, totaling 2 hours of lectures for each series.

The participants were allowed to make questions at any time. During the lecture, the use case model purpose and importance were discussed. After that, the use case model elements were presented in the following order: use case, actor, association, dependence (inclusion and extension), and inheritance. Each element had its definition and semantic in the model discussed. Then, following the participants' suggestions, a Use Case model for a library system was created.

After the lecture, participants had to work in groups in an activity of system modeling. To perform the group activity, they received a restaurant order system description to model using use cases. The features were divided equally among the participants

and each one had to create the actors, use cases, and relationships related to the features received.

Finally, participants had to answer a post-lecture questionnaire with questions about inclusion and learning. The questionnaire was composed of open-ended questions, Likert-scales (from “strongly disagree” to “strongly agree”), and one related to the general perception about Model2gether accessibility (from “very bad” to “very good”).

To the participant with blindness, the questionnaire was composed of 20 items, 5 of them were Likert-scales, 1 about Model2gether accessibility (from “very bad” to “very good”), and the other 14 were open-ended questions. Among the questions were:

- (i) Explain what you understand by 'inclusion';
- (ii) In relation to your understanding about inclusion, consider the statement "I consider myself included in the lectures" and select one of the following alternatives (Likert-scale);
- (iii) Explain the reasons of your answer in the previous question;
- (iv) Considering your understanding of the lecture content, evaluate the following statement "I understood the content taught in the lectures" (Likert-scale);
- (v) Regarding your understanding of inclusion, evaluate the statement "I considered myself included in the group activity with other students".

There were 12 questions to the sighted participant, 1 of them was Likert-scale, 1 about Model2gether usability, and the other 10 were open-ended questions. They answered the same questions concerning their knowledge about the subject to check their learning improvement after the lectures. The answers were assessed and they received a grade from 0 to 10. Among the questions were:

- (i) Considering your understanding about the lecture content, evaluate the following statement "I understood the content taught in the lectures" (Likert-scale);
- (ii) Can you definitely indicate if at least one of your co-workers was visually impaired?;

- (iii) If you have already attended a use-case lecture, what was the change in the dynamics in relation to these lectures?

9.5 Test results

Among the 5 participants of the first series of lectures, 3 of them (representing 60%) were evaluated with grade 5 or lower in relation to their previous knowledge about requirements specification and use case modeling. The other 2 participants were scored 6.7 and 7.1. The most common errors of the participants concerned relationships between use cases, especially dependency and generalization relationships. After the lectures, all participants increased their grades. The average increase for the first group was 2.3 points. Each participant score is presented in Table 11.

Table 11: First series participants' grades before and after the lecture.

Participant	Grade before (previous knowledge)	Grade after
#1	3.9	7.5
#2	7.1	7.1
#3	5	8
#4	6.7	7.5
#5	3.2	7.5

The diagrams produced in the group work presented no errors and were suitable for the specified system description. These results show that the lectures contributed to the participants' learning about the subject.

With regard to *inclusion process*, the participant with blindness of the first series was asked about what he understands by inclusion and whether he felt himself included in the lectures. According to him, inclusion can be defined as "the possibility of carrying out activities under equal conditions. This does not mean doing the same thing as another person in the same way, but rather is related to maximizing the inherent abilities and perceptions of each."

Considering accessibility, he strongly agreed (5 in a scale range from 1 to 5) with the affirmation "I felt myself included in the lectures and group work". Besides, he strongly agreed with the affirmation "I understood the lectures content".

The most interesting result was that none of the sighted participants noted that

there was a participant with blindness in the lecture and in the group work, indicating that the tool gave the necessary support to the blind individual in order to increase his abilities and perceptions.

Still regarding the used tools, participants evaluated that the coordination and visibility mechanisms of Model2gether contributed to the conduction of the lecture. For participants who have already attended lectures on the same subject in face-to-face courses, no difference was noted in the lectures dynamics due to the participation of the visually impaired.

For the second series, among the 5 participants, 2 of them (representing 40%) were evaluated with grade 5 or lower in relation to their previous knowledge about requirements specification and use case modeling. The other 3 participants were scored 5.3, 6.4, and 7.1. The most common errors of the participants also concerned relationships between use cases, especially dependency and generalization relationships. After the lectures, all participants increased their grades. The average increase for the second group was 3.3 points. Each participant score is presented in Tables 12.

Table 12: Second series participants' grades before and after the lecture.

Participant	Grade before (previous knowledge)	Grade after
#6	4.3	6.3
#7	7.1	10
#8	4.3	10
#9	6.4	10
#10	5.3	7.8

With regard to *inclusion process*, the participant with blindness of the second series defined it as "Inclusion is a process by which people, even with their particularities that differentiate them from the group to which they belong, can move around in the spaces, participate in the activities, with the best possible condition, since the spaces and activities were designed for this purpose, or adapted.."

Considering accessibility, he agreed (4 in a scale range from 1 to 5) with the affirmation "I felt myself included in the lectures" and neither agreed nor disagreed (3 in a scale range from 1 to 5) with the affirmation "I felt myself included in the group work". According to him, the reason for the grade 3 regarding the group work was the perception of auditory overload due to many messages coming from many people and

many channels. He agreed with the affirmation “I understood the lectures content”.

As for the first group, none of the sighted participants in the second group realized that there was a participant with blindness in the lecture and in the group work, reinforcing that the tool gave the necessary support to the blind individual in order to increase his own abilities and perceptions.

Additionally, for participants in the second group who have already attended lectures on the same subject in face-to-face courses, no difference was noted in the lecture dynamics due to the participation of someone with blindness.

Considerations

After conducting user tests involving participants with blindness and sighted participants in an e-learning scenario mediated by Model2gether combined with a synchronous communication service, results indicate that participants with blindness feel themselves included in online lectures. Nevertheless, they still felt uncomfortable with the information overload caused by the adoption of continuous awareness during the lecture. The evaluation was reported in a conference paper (LUQUE et al., 2017).

As a conclusion, although following all inclusion requirements existing in the literature at that time, there was still problems concerning the inclusion of individual with blindness in such an educational setting. This fact brought initial evidence about the need for a method to support the (re)design of accessible and inclusive groupware.

10 COLLAB4ALL

Having evidence about the need for formal support to (re)design accessible and inclusive groupware, we conducted a second systematic review to confirm it. The review is detailed in Appendix A.

The review results show that, when considering the inclusion of individuals with impairments in CSCW, there are papers related to different types of impairments, such as hearing impairment (ANGKANANON; WALD; GILBERT, 2015; BARRETO; DEUS; APOLONIO, 2010), dyslexia (LAKOV, 2004), visual impairment (JATOBÁ et al., 2009; KANJO; ASTHEIMER; MARSHALL, 2004), physical impairment (KARDUCK, 2000), to cite just a few.

Nevertheless, none of them adopts collaboration-oriented methods to support design or redesign of accessible and inclusive groupware. In order to fill this gap we developed Collab4All. This chapter is devoted to describe it.

10.1 Definition and Objective

Collab4All is a method aimed at supporting the identification of accessibility challenges and alternative solutions that may arise in groupware due to the inclusion of individuals with impairments. Accessibility is understood in the method as the extent to which groupware can be used by users with specified disabilities to achieve predetermined goals with effectiveness, efficiency, freedom from risk, and satisfaction in a specified context of use (ISO, 2011b).

10.2 Usage scenarios

The method was developed with two main scenarios in mind: (i) collaborative activities currently not mediated by computers that need to be shifted to computer-mediated settings - due to the inclusion of individuals with impairments, for example; and (ii) collaborative activities already mediated by computers that require a more accessible groupware in order to include individuals with impairments. While the former scenario

is oriented to designing new groupware, the second involves evaluating existent groupware and subsequently redesigning it. These two scenarios involve the possibility of joint work involving both people with and without impairments.

10.3 Principles

The method comprises an overarching set of principles, described next:

- Accessibility is handled in levels;
- Driven by individuals' impairments and disabilities;
- Independence of underlying software engineering methods and processes.
- Oriented to fulfill accessibility-related quality requirements;
- Work is done through iteration.

In the following subsections we describe what we mean by each principle.

10.3.1 Accessibility in handled in levels

Collab4All establishes four accessibility levels that must be addressed by groupware designers and evaluators. These levels are organized one inside another, similarly to Matryoshka Russian dolls (ARENA et al., 1996). This organization was chosen to indicate that the accessibility of an inner level is not sufficient when an outer level has accessibility barriers. The two most outer levels are related to accessibility from the point of view of both individual and collaborative activities. The two inner levels, in turn, are related to collaborative activities only. Figure 20 illustrates these levels and their relations.

The most outer level is related to environment accessibility. If a collaborative activity must be performed in a specific environment (e.g. a specific classroom), the accessibility of that environment play a central role in inclusion. For instance, lighting conditions, background noise, furniture size, doorway wideness, and stairs are among the factors that may influence the inclusion of individuals with impairments (ANGKANANON;

Figure 20: The four Collab4All accessibility levels (Source: author)

WALD; GILBERT, 2015). If participants with impairments cannot access or stay in the environment, the inclusion process cannot be further conducted to inner levels. When considering remote activities, individuals generally already have an accessible environment. Nonetheless, the internet connection quality on the participant side may be seen as an environmental factor that affects inclusion.

Assuming that the activity environment is accessible, as Collab4All focuses on computer-supported activities, the computational resources must be accessible for individual use by all participants. In other words, if a groupware has accessibility barriers for individual use, it cannot be used collaboratively.

Given that no barriers have been found in previous levels, the accessibility of computer-mediated interaction may be taken into consideration. In a collaborative context, interaction is generally related to communication, coordination, cooperation, and awareness. The pure accessibility of a groupware when considering individual use (previous level) may not be enough (WINBERG; BOWERS, 2004).

Finally, the most inner level is related to the accessibility of interactions between participants not mediated by computers when co-located. Many times, this cannot be completely achieved and it is not necessary.

10.3.2 Driven by participants impairments and disabilities

The method is driven by the influence participants' impairments have in their skills and knowledge, and how this impacts different aspects of collaborative activi-

ties. Impairment-related information is used jointly with MHP(see chapter 5) in order to analyze possible challenges that may arise from the participation of individuals with impairments in collaborative settings. Information about disabilities may also be used with the same purpose.

10.3.3 Independence of underlying software engineering methods and processes

The Collab4All activities are mainly related to problem exploration, analysis/evaluation of potential challenges, and exploration of alternatives. During these activities, the implementation or modification of prototypes/products may be required. Any preferred software development method and process may be used to achieve this specific goal. In this sense, Collab4All plays the role of a complementary method that can be used together with other software engineering methods and processes.

10.3.4 Oriented to fulfill accessibility-related quality requirements

Collab4All takes into consideration the individuals' impairments in order to support analysis, specification, evaluation, and adaptation of collaborative activity-related aspects to the maximum extent in which the results are still valuable. Value here is understood in terms of activity goals, effectiveness and efficiency. Participants must also feel themselves included, satisfied, and free from risk.

10.3.5 Work is done through iteration

The method must be conducted iteratively. Each iteration may address one or more accessibility levels, generally following a path from outside to inside. Each iteration goes a step further in understanding the problem space, analyzing/evaluating potential challenges that may arise from the inclusion process, and exploring alternative solutions to overcome the identified challenges.

10.4 Collab4All General Workflow

In order to provide a general view of the method flow, we present the Collab4All general workflow, by detailing its main activities textually and diagrammatically, with the UML activity diagram with stereotypes.

10.4.1 Work breakdown structure and notation

The method *Work Breakdown Structure* (WBS) and the notation we used in its specification are similar but not exactly equal to those used in the IRUP. The WBS comprises: iterations, activities, subactivities, and tasks. It is at task level that a unit of work happens. It involves the participation of one or more individuals that play specific roles. They may use input artifacts and resources, generally groupware, to produce resulting artifacts. Activity diagrams were used to illustrate the general workflow and IRUP-related diagrams were used to detail activities.

10.4.2 Activities

Each method iteration comprises 3 activities, as shown in Figure 21. At the first iteration, these activities are: (i) Explore Problem; (ii) Analyze Potential Challenges; and (iii) Explore Alternatives. Subsequent iterations involve the same activities, but with different names. This difference does not reflect in activity purpose and was introduced only to highlight that the method is not at the first iteration.

The sequential representation of these activities is used only to clarify that before exploring/refining alternatives, it is necessary to have analyzed/refined some potential challenges. In turn, to do that, it is necessary to have established a minimum understanding about the problem.

In fact, when applied, these activities will probably be performed in parallel: while one is refining the problem exploration, other may be analyzing a potential challenge or exploring alternatives for another challenge. Figure 22 illustrates the parallelism that may happen between activities.

The next subsections present details about each activity.

Figure 21: Collab4All general workflow (Source: author)

10.5 Explore Problem/Refine Problem Exploration

The first activity involves exploring the problem space. It is a common activity at the beginning of many software development process models (PURA0; ROSSI; BUSH, 2002). As expected, context plays an important role on the accessibility of collaborative activities (LIU; DAI, 2008). The main difference between the problem exploration we propose in Collab4All and those found in other software processes models and

Figure 22: Expected parallelism between Collab4All activities (Source: author)

methods is the focus on activity decomposition and the establishment of relationships between participants' profile, MHP, and collaboration aspects.

Figure 23 illustrates the tasks that must be performed in this activity, as well as related roles and artifacts.

Figure 23: Tasks, artifacts and roles involved in the 'Explore Problem' activity (Source: author).

Potential accessibility challenges may arise from various aspects of the problem space, such as:

- (i) the activity goals;
- (ii) the environment where it will be performed;

- (iii) the participants' profile;
- (iv) the inclusion goals;
- (v) the tasks that compose the activity, their dynamics, and what skills/knowledge are needed to perform them.

The activity goals may be seen as the collaborative work guiding thread. Consequently, they are the starting point to be considered when seeking to promote inclusion in CSCW. Ultimately, the adaptations made to a collaborative activity may change some or all of its tasks, but these changes must not result in outcomes different from those expected for the activity. Furthermore, goals that specify restrictions, such as quality attributes (e.g. activity timing and resource optimization), may reduce the room for maneuver in activity adaptation. For instance, an activity that requires rapid feedback from participants (e.g. about 240ms) may hinder the inclusion of individuals with motor impairment or even make it impossible without changing this restriction.

Another aspect that may influence collaborative activities is the environment. The identification of the activity goals, restrictions, as well as information about the environment are part of the Collab4All *Analyze Activity Context* task. The main roles involved in this task are of *Collaboration Designer*, a researcher or anyone interested in design an inclusive collaborative scenario, and *Domain Specialist*, anyone that has experience on the activity domain. A variety of activity-related documents may be useful as information sources for this task, such as: (i) existing training materials; (ii) task observation records; (iii) protocol descriptions, among others.

Table 13 may be used to register activity goals and environment-related information.

In parallel to the activity context analysis, it is necessary to explore participants' profile. It may be seen as an independent variable of collaborative activities since it cannot be changed. As observed by Lopresti et al. (2004), any assistive technology for people with disabilities must accommodate the individual user's skills and deficits.

Each participant impairment, with detailed information about what MHP components it affects, must be registered in order to allow a latter challenge analysis. Sometimes, information about disabilities does not include details about the way it affects

Table 13: Activity Context Table

Name:	
Description:	
Goals	
Expected Outcomes	
* Expected outcome A;	
* Expected outcome B.	
Restrictions	
<i>Category</i>	<i>Description</i>
(e.g. Time)	Restriction description
Environment	Address: Usage: Physical Characteristics:

MHP components, but the way it affects specific skills or knowledge. This is also relevant and must be registered. Information about whether it is a birth-impairment or result of a latter event, as well as gender, age, emotional status and culture are also relevant for inclusion. The identification of such information is part of the Collab4All *Explore Participants' Profile* task. In addition to the *Collaboration Designer* and the *Domain Specialist*, this task involves participants with and without impairments. Among the documents and techniques that can be used in order to identify the required information are: (i) interviews; and (ii) surveys. The literature on the specific impairment and disability as well as observations may also be a useful source of information. At initial iterations, participants may be clustered in groups. Table 14 may be used to register participants profile. The relation between impairments and MHP components may both be represented graphically (Figure 24) and using a table (Table 15)

The break-even aspect of the activity context and the participants' profile is the inclusion goals. They depend on the activity context but are constrained by the participants' profile. For instance, if the collaborative activity under consideration involves including a learner with visual impairment in a statistics class, the ultimate inclusion goal is to offer to all learners, independent of any impairment, equal opportunities to develop their skills and competencies related to the subject. When conflicts arise from inclusion goals, moral and legal priorities may be followed in order to define, for example, if a restriction must be relaxed in order to achieve the inclusion goals. The definition and specification of the inclusion goals are part of the Collab4All *Define Inclusion Goals* task. The predominant role in this case is the *Collaboration Designer*

Table 14: Participants Profile Table

Name:	
Role:	
Age:	
Gender:	
Education level:	
Cultural characteristics:	
Impairments	
<i>Description</i>	<i>Birth or Latter Event</i>
Disabilities	
<i>Description</i>	<i>How It Affects Skills and Knowledge</i>
Experience	
With the collaborative activity:	
With software:	
With the used groupware:	

Table 15: Effects of impairments in MHP components table

Impairment	MHP Component	How It Affects the MHP Comp
Impairment A	MHP Comp. A and B	Description

one.

Finally, it is important to identify sub-activities and also tasks, since they are the activity decomposition elements in which cooperation happens and consequently in which inclusion obstacles may appear. In this context, it is necessary to decompose the activity into its constituent tasks, subgoals, and to identify the skills and knowledge required to support task execution. Some of the aforementioned activity-related documents may be used as information sources to identify tasks, such as training materials and observation records. Also, well-known techniques such as Hierarchical Task Analysis (HTA) (KARWOWSKI, 2006) and the GOMS model family (JOHN; KIERAS, 1996) may be useful. The tasks can be described textually and using a task diagram, representing the tasks and their relationships. For each task, it is necessary to identify what skills and knowledge are required to perform it properly. The interaction between participants mediated and non-mediated by groupware, may be represented through a diagram such as the one of Figure 25. It represents interactions that take place between a specific participant, other participants, and groupware, as well as the main purpose of interactions (coordination, awareness etc.). It also may be represented using a table for each participant (see Table 16). Table 17 may be used to document

Figure 24: Impacts of MHP components by impairments (Source: author).

task-related information.

Table 16: Interactions between participants, artifacts, and resources table.

Interacting with	Type	Description
B	Awareness	Awareness of B actions to modify the artifact X.
Groupware	Muscular Action	Change an artifact element position.

Information about dependencies between tasks and MHP components may also be registered through three tables described next. Table 18 is the table that establishes the dependencies between senses and task steps. It specifies what kind of information related to the task must be obtained. Table 19 is the table that establishes what type of memory is dominant for the task steps. Finally, Table 20 is the table that establishes how each processor is used for in the task steps.

Figure 25: Example of collaboration-related interaction in a task (Source: author).

Table 17: Task Table

Name:	
Description:	
Precedence: Tasks that must have finished, started etc. before this one starts/finishes	
Goals	
Expected Outcomes	
* Expected outcome A; * Expected outcome B.	
Restrictions	
<i>Category</i>	<i>Description</i>
(e.g. Time)	Restriction description
Required Skills and Knowledge	
<i>To do</i>	<i>Requirements</i>
Something to do	Required skills and knowledge

Table 18: Senses vs. Collaboration Components

To Do	Sight	Hearing	Touch	Smell	Taste	Proprioception
[]						
[]						
[]						
[]						

This information is part of the Collab4All *Decompose Activity into Tasks* task. Both the *Collaboration Designer* and the *Domain Specialist* play a relevant role in this task.

Table 19: Dominant memory in task table

	To Do	Dominant
[]		
[]		
[]		

Table 20: How each processor is used

	To Do	Use	
[]			
[]			
[]			

Figure 26 updates the collaborative work components illustrated in chapter 3 and the relationships among them.

Figure 26: Collaboration domain metamodel (Source: author).

10.5.1 Analyze/Refine Potential Challenges

The information gathered through problem space exploration may now be used to analyze potential challenges that may arise in collaborative activities due to the participation of individuals with impairments. This is the second Collab4All activity. Figure 27 illustrates the tasks that must be performed in this activity, as well as related roles and artifacts.

At environment accessibility level, a set of questions may be used to identify possible challenges (see Table 21).

Figure 27: 'Analyze Potential Challenges' activity (Source: author).

Table 21: Environment-related questions to identify potential challenges

Questions Related To	Question
External Factors	Is there accessible public transportation to the environment place?
	Is the path from the public transportation stop to the environment place accessible?
General	Are there persons available to ask information?
	Does the place have proper lightning conditions?
	Does the place have unavoidable background noises?
Physical Impairment	Is the place plane or does it have ramps/lifts?
	Do ramps/stairs/walkways have handrails?
	Is the entrance doorway width enough to different wheelchair sizes?
Visual Impairment	Does the place have Braille/tactile panels or sound identification?
	Is the path way floor pavement different from surroundings?
Hear Impairment	Is there information available only through audio?
	Do the person available to ask information know how to use the sign language?
Color Blindness	Does the place use colors in order to identify specific rooms or details?

For other levels, a set of mappings must be performed in order to identify potential challenges related to the participation of individuals with impairments in CSCW. As aforementioned, Collab4All is based on MHP in order to identify these potential challenges. Figure 29 introduces a MHPComponent to the Collaboration Domain Meta-

model of Figure 26 and highlights existing dependencies among it and collaborative work components.

When considering both groupware accessibility for individual and collaborative use, MHP components may be seen as the glue that partially connects participants' profiles to tasks and related elements - participation, environment, quality attribute, artifact, and resources. Figure 28 illustrates such relation.

Figure 28: Relation between collaboration and MHP components (Source: author).

Specifically at level of individual use, traditional accessibility models and evaluation may be conducted. It includes checking conformance to reference models, conducting usability tests and heuristic evaluations.

Additionally, information about impairments may be used to mark what task step may be hindered. The brackets in tables 18, 19, and 20 may be used to register such information. Additionally, each skill and knowledge that may be affected by an impairment or disability may be related to the skills and knowledge required to perform the task steps.

For collaboration aspects, both mediated and non-mediated by computers, we defined a set of questions that must be made in order to verify possible challenges that may arise from the participation of people with impairments in collaborative activities. For each interaction that may happen between participant-participant, participant-groupware, participant-groupware-artifact, and participant-groupware-participant (see Table 16 and Figure 25), the questions described in next subsections may be used to identify potential challenges.

Figure 29: Dependencies between collaborative work and MHP components (Source: author).

Communication

Considering the relation between communication and MHP described in chapter 3, it is straightforward to identify some possible challenges that may arise if someone with an impairment participates in a collaborative activity. These challenges may be explored through the guiding questions in Table 22. This table presents questions, the most affected accessibility-related quality attribute, and the MHP components that may affect the answer to the question, if impaired.

Coordination

Regarding coordination, in addition to what was discussed about the communication process, the guiding questions presented in Table 23 may help one to identify possible challenges that may arise from the participation of a person with an impairment into a collaborative activity.

Cooperation

While cooperation depends on the activity context under consideration, we suggest making the questions represented in Table 24.

Awareness

The awareness-related questions varies from activity to activity. However, we suggest making the questions represented in Table 25.

General questions

In addition to these questions, it is important to make the same questions that incorporate different collaboration mechanisms and different tasks (Table 26):

Table 22: Communication-related guiding questions, the most affected accessibility-related quality attribute, and the MHP components that may affect the question answer if impaired.

[illegible]

Table 23: Coordination-related guiding questions, the most affected accessibility-related quality attribute, and the MHP components that may affect the question answer if impaired.

[illegible]

Table 24: Cooperation-related guiding questions, the most affected accessibility-related quality attribute, and the MHP components that may affect the question answer if impaired.

[illegible]

Table 25: Awareness-related guiding questions, the most affected accessibility-related quality attribute, and the MHP components that may affect the question answer if impaired.

[illegible]

Table 26: General questions and considerations.

Question	Quality Attribute	Perceptual Processor	Cognitive Processor	Motor Processor	Sensorial Memory	Working Memory	Long-Term Memory	Sensors	Muscles
How many sources of information must a participant deal with?	Effectiveness	✓			✓	✓		✓	
How many items must be stored in the working memory for specific tasks?	Effectiveness					✓			
May the number of information sources and the items that must be stored in the working memory overload the participant?	Effectiveness					✓			
Does the participant mental model contributes to performing the task?	Effectiveness	Do Not Apply							

10.5.1.1 Answering these questions

In order to answer these questions, there are some options. Firstly, the literature related to the participant impairment/disability may be consulted. When the question addresses information volume, processing time, and memory capacity, literature related to the MHP may be consulted. For some other questions, such as those related to safe from risk, small pilot tests/experiments are generally required.

When there is doubt about an answer to the question, even after following one of these suggestions, the challenge may be assumed as real and incorporated as alternative configurations in the groupware. Therefore, if the challenge is identified during a test/experiment, the groupware may be rapidly adjusted to offer an alternative solution. When experiments or tests have to be conducted, it is important to properly plan them, preparing the environment, training the supportive staff, and other related infrastructure. It is also important to prepare accessible consent terms.

10.5.2 Explore Alternatives

The *Explore Alternatives* activity contains only one task with the same name. The main role involved in such task is of *Collaboration Designer*.

The tables defined in the last step and the answers to the questions may be used to identify which tasks will be affected by the impairment. After identifying possible challenges, the questions proposed in Tables 27 (communication challenges), 28 (coordination challenges), 29 (cooperation challenges), and 30 (awareness challenges) may help finding or proposing solutions to the problems. Based on these alternatives, tests and experiments may be planned or requirements may be specified and implemented using any software engineering method. Challenges related to general questions may be handled with similar questions.

Table 27: Alternatives to be explored if a communication challenge has been found.

Question	Alternatives
What sensors are required to learn the communication code? Is the participant able to use these sensors?	<ul style="list-style-type: none"> - Is it possible to make this code available through other sensors? - Is there any automatic conversor that translates the learning material to other sensors? - Is there people available to make this conversion? - Are the tools and method used to teach the code appropriate?
How many communication rules must be stored? Is the participant able to store this ammount of information?	<ul style="list-style-type: none"> - Are all rules required for the specific task? - May the code be simplified? - Is it possible to train other participants in order to cooperate without some communication rules? - Is there any computational support to supplement that?
Is the participant able to memorize the code during the whole task?	<ul style="list-style-type: none"> - Is it possible to make interruptions during the task to remember about parts of the code? - Is there any computational support to supplement that?
Is the participant able to properly encode messages?	<ul style="list-style-type: none"> - May the code be simplified? - Is there a computational support to supplement that?
Is the participant able to send messages using muscles?	<ul style="list-style-type: none"> - Are there other codes that may be used (e.g. gestures in replacement for words)? If yes, are these codes sufficient to transmit the message?
Is the participant able to properly decode messages?	<ul style="list-style-type: none"> - Is it possible to use an automatic translator from the current code to a more palatable one? - Is there people available to decode the message and conveys it to the participant?
Is the participant able to receive messages using sensors?	<ul style="list-style-type: none"> - Is there any automatic conversor that translates messages to other sensors (e.g. computer vision to identify gestures and synthesize them; audio to sign language conversors)? - Is there people available to make this conversion? - May other participants send these messages to other sensors (e.g. verbally communicating what is being pointed)?
Is the time required to process messages appropriate to the task dynamics?	<ul style="list-style-type: none"> - May the task dynamics be modified? Otherwise, inclusion in such task may not be possible? - Is the participant aware of this? - Can this affect the health of the participant?
Is the time required to produce messages appropriate to the task dynamics?	
Is the communication process effortless?	
Is the communication process safe from risk to the participant?	

Table 28: Alternatives that may be explored if a coordination challenge has been found.

Question	Alternatives
What sensors are required to learn the coordination rules? Is the participant able to use these sensors?	<ul style="list-style-type: none"> - Is it possible to make this code available through other sensors? - Is there any automatic conversor that translates the learning material to other sensors? - Is there people available to make this conversion? - Are the tools and method used to teach the rules appropriate?
How many coordination rules must be stored? Is the participant able to store this ammount of information?	<ul style="list-style-type: none"> - Are all rules required for the specific task? - May they be simplified? - Is it possible to train other participants in order to cooperate without some communication rules? - Is there any computational support to supplement that?
Is the participant able to memorize the coordination rules during the task?	<ul style="list-style-type: none"> - Is it possible to make interruptions during the task to remember about parts of the rules? - May the groupware coordinate participation? - Is there any computational support to supplement that?
Is the participant able to respect the proper moment to act and communicate? Does the participant have the cognitive skills required to relate collaborative activity awareness information to coordination rules?	<ul style="list-style-type: none"> - May the groupware inform when the participant is authorized to act and communicate? - May someone inform when the participant is authorized to act and communicate? - Investigate how the participant deviation from the expected behavior harms the collaborative activity.
Is the time required to coordinate appropriate to the task dynamics?	<ul style="list-style-type: none"> - May the task dynamics be modified? Otherwise, inclusion in such task may not be possible?
Is the time required to process coordination orders appropriate to the task dynamics?	
Is the coordination process effortless?	<ul style="list-style-type: none"> - Is the participant aware of this?
Is the coordination process safe from risk to the participant?	<ul style="list-style-type: none"> - Can this affect the health of the participant?

Table 29: Alternatives that may be explored if a cooperation challenge has been found.

Question	Alternatives
What sensors are required to learn about how to use resources and access artifacts? Is the participant able to use these sensors?	<ul style="list-style-type: none"> - Is it possible to make this information available through other sensors? - Is there any automatic conversor that translates the learning material to other sensors? - Is there people available to make this conversion?
What sensors are required to use the resources?	
What sensors are required to access artifacts?	
What muscles are required to use the resources?	<ul style="list-style-type: none"> - Is it possible to manipulate the resources and artifacts using different muscles (e.g. voice commands if a motor or visual impairment is present)? - Is it possible to have someone using the resources and changing artifacts based on the participant orders? - Is it possible to modify the resources and artifacts?
What muscles are required to change artifacts?	
Does the participant have the cognitive skills required to cooperate?	- Is it possible to simplify his/her participation in the task?
Is the time required to cooperate appropriate to the task dynamics?	- May the task dynamics be modified? Otherwise, inclusion in such task may not be possible?
Is the cooperation process effortless?	- Is the participant aware of this?
Is the cooperation process safe from risk to the participant?	- Can this affect the health of the participant?

Table 30: Alternatives that may be explored if an awareness challenge has been found.

Question	Alternatives
What sensors are required to be aware of changes in artifacts? Is the participant able to use these sensors?	<ul style="list-style-type: none"> - Is it possible to make this information available through other sensors? - Is there any automatic conversor that translates the learning material to other sensors? - Is there people available to make this conversion?
What sensors are required to be aware of what others are doing? Is the participant able to use these sensors?	
What sensors are required to be aware of resources feedback? Is the participant able to use these sensors?	
Is the participant able to memorize what others are doing?	<ul style="list-style-type: none"> - May the groupware provide this information to participants? - May this information be updated before beginning the task? - May someone help the participant providing this information?
Is the participant able to memorize changes in artifacts?	
Is the participant able to relate awareness information with other collaboration components?	<ul style="list-style-type: none"> - May someone offer support regarding that? - May the groupware offer support regarding that?
What awareness information must the participant store to perform the task? Is the participation able to memorize this information	<ul style="list-style-type: none"> - May the groupware provide this information to participants? - May this information be updated before beginning the task? - May someone help the participant providing this information?
Is the time required to process awareness information appropriate to the task dynamics?	- May the task dynamics be modified? Otherwise, inclusion in such task may not be possible?
Is the awareness process effortless?	<ul style="list-style-type: none"> - Is the participant aware of this? - Can this affect the health of the participant?
Is the awareness process safe from risk to the participant?	

Considerations

In this chapter we presented Collab4All, a method to foster the inclusion of individuals with impairments in CSCW. Its rationale is the establishment of dependencies between MHP components, collaborative components, and tasks requirements. A panorama of Collab4All was published in (LUQUE; BRANDÃO; BRANDÃO, 2017). A paper detailing the method is being prepared for submission to a scientific journal.

In the next chapter we describe a proof of concept for the method viability.

11 PROOF OF CONCEPT

After defining Collab4All, we performed a proof of concept with the aim of verifying that it has practical potential. We sought to show that Collab4All could have helped us when designing Model2gether for the first time but that it could also help us in redesigning it.

11.1 Applying Collab4All

For applying Collab4All, the author of this thesis played the roles of collaboration designer and domain specialist.

We decided to address one of the activities related to the challenge that motivated this research. The activity context comprehends remote collaborative diagramming involving individuals with blindness. Table 31 presents details about the activity context.

Table 31: Context of the application scenario

Name: Collaborative and Remote Editing of UML Use Case Diagrams	
Description: This activity comprises the creation of UML Use Case diagrams remotely and collaboratively. It involves an individual with visual impairment and another one sighted working together in real-time.	
Goals	
Expected Outcomes	
A Use Case diagram representing the software functional requirements of a system.	
Restrictions	
<i>Category</i>	<i>Description</i>
Place	Each participant would participate remotely using a computer
Time	1 hour
Environment	The activity will be performed using the Model2gether for cooperation, awareness, coordination, and non-verbal communication. Verbal communication would be established using the VoIP service. .

Two distinct groups participated in the activity: 4 individuals with blindness and a sighted individual. The 4 individuals with blindness were invited from the same list as for the first iteration. The sighted participant had more than 11 years of experience teaching object-oriented modeling with UML and had previous experience teaching individuals with blindness in traditional classroom. In order to identify relevant

information about the participants profile, they were asked to answer a questionnaire.

Table 32 shows the participants' profile. The questions were about their:

- (i) age;
- (ii) gender;
- (iii) previous experience with screen readers (for participants with blindness);
- (iv) previous experience with the model addressed and its related concepts;
- (v) blindness condition - since birth or acquired later (for participants with blindness)

Table 32: Participants' profile.

Participant	Age	Gender	Blindness	Previous Experience with		Used Screen Reader
				Screen Readers	Use Case Models	
#1	31	Female	Acquired (11 years ago)	10 years	Basic	Jaws and NVDA
#2	36	Male	Birth	17 years	None	Jaws and NVDA
#3	22	Male	Acquired (20 years ago)	10 years	Advanced	NVDA
#4	33	Male	Acquired (20 years ago)	10 years	Basic	NVDA
#5	34	Male	Sighted	NA	Advanced	NA

The inclusion goal was to allow individuals with blindness and sighted individuals to work collaboratively while creating use case diagrams, feeling themselves included and satisfied.

In order to identify the tasks that compose the activity, we conducted a high-level hierarchical task analysis and identified many tasks. Some of them are illustrated in Figure 30.

Figure 30: Part of the hierarchical task analysis of the example activity (Source: author).

Table 33: Description of the task "Point to" an element.

Name: "Point to" an element	
Description: A movement sighted individuals generally does for pointing at an element in order to contextualize what will be said next.	
Precedence: This task is generally performed before and together with describing an element.	
Goals	
Expected Outcomes	
* Contextualizing what is going to be described.	
Restrictions	
<i>Category</i>	<i>Description</i>
None	
Required Skills and Knowledge	
<i>To do</i>	<i>Requirements</i>
Identify the position of the element that will be pointed	Properly locate elements through sight.
Give instructions so that other participants can identify the element	Clicking over the element.

11.1.1 Analyzing Possible Challenges

Firstly, we focused our attention on a specific task: point to an element. This task appears in the *Ask Question About Specific Element* subactivity. This task is related to a movement sighted individuals generally does for pointing at an element in order to contextualize what will be said next. For instance, a participant can point at a diagram element and ask 'Do you think this element is properly related to that one?' or 'This element represents the concept X'. Table 33 describes this task.

Tables 34, 35, and 36 were created for this task.

The task involves two main steps, mentioned in Table 33:

- Identify the position of the element that will be pointed;
- Give instructions so that other participants can identify the element.

Table 34: Senses vs. Collaboration Components

	Sight	Hearing	Touch	Smell	Taste	Proprioception
Communication	X					
Coordination	X	X				
Cooperation						
Awareness	X					

Table 35: Dominant memory in task

	Dominant
Working Memory	
Long-Term Memory	X

Table 36: How each processor is used

	Use
Perceptual Processor	Visual perception of the pointing movement and the diagram
Cognitive Processor	Translate the pointing direction to a diagram element
Motor Processor	Follow the participant with eyes

It also involves the following collaboration components:

- Non-verbal communication - the "point to" gesture itself;
- Coordination - the participant pointing to should be the one receiving attention;
- Awareness - other participants must be aware of what element is being "pointed to" and its neighborhood;
- Cooperation - the cooperation is a result of a larger process that involves this task.

Using Collab4All questions, it is possible to identify the following challenges that may arise from the participation of individuals with blindness in such activities. Also, considering the sense-related task requirements, as shown in Table 34, it is possible to verify a high dependency on the sense of sight.

- Is the participant able to receive messages using sensors?
Participants with visual impairment cannot see visual feedback indicating which element is selected;
- What sensors are required to be aware of what others are doing? Is the participant able to use these sensors?
Vision is required to follow which element is selected. As individuals with visual impairment cannot see, a challenge arise from that.

- What sensors are required to be aware of the artifacts and changes made to it?
The participant require the sense of sight to identify the position of an element that must be pointed to.

Considering this, a groupware to support such type of interaction must support alternatives to convey the pointing movement-related information to the individual with blindness. Using audio feedback about what is being done by others is an alternative. Moreover, allowing the participant with blindness to point to an element by selecting it and choosing a menu option or pressing a shortcut is an alternative. This was a point we had already addressed in Model2gether, but was not addressed in the studies in the literature (See appendix B).

While analyzing these alternatives, two questions called our attention:

- How many sources of information must a participant deal with?
- May the number of information sources and the items that must be stored in the working memory overload the participant?

It reminded us of the problem one of the participants mentioned during the first iteration user tests.

In the literature review, we noticed none of the studies covered information overload when analyzing interaction of individuals with blindness with UML diagrams. In fact, during the task, the individual with impairment have to deal with the sources of information presented in Table 37.

Also, tables 35 and 36 are useful to identify that the adopted strategy would cause overload on the working memory and perceptual processor.

Based on this finding, we changed the system to allow participants with blindness to control how much and when they would like to received auditory feedback about what himself and other participants were doing during the activity. They could, for instance, hear only a beep sound when the lectures pointed at an element and then, if necessary, discover which element has been selected.

We had to update Model2gether so that it could support different awareness levels.

Table 37: Interactions and sources of information that a participant must deal with.

Interacting with	Type	Description
Sighted Participant	Awareness through audio messages	The element to which the participant is pointing to.
Sighted Participant	Verbal Communication	Description of the element being pointed to.
Artifact	Awareness	Accessing the artifact to navigate through the pointed element and its neighborhood.
Resource	Awareness	Audio feedback about the groupware interface elements

We customized the tool to support 3 different interfaces regarding awareness and non-verbal communication mechanisms.

- If the user checks "Follow model updates", he/she receives text messages (e.g.: A new use case was created: Borrow Material) every time another user changes the model (visual changes are not reflected to people with blindness) and another user points to an element - continuous notification.
- If the user checks "Listen to beeps when changes are made to the model", beeps are produced when another user changes the model - reduced continuous notification.
- Another possibility is to uncheck these options and not receive any awareness and non-verbal communication information.

11.2 Evaluation

In order to analyze the effect of applying Collab4All to guide the redesign of Model2gether, we conducted a user test of Model2gether with blind-sighted pairs. The test involved the evaluation of three different audio/speech output interfaces. We adopted a master-master coordination and verbal communication using a synchronous communication service. Object awareness, one's own action feedback, coordination signals and non-verbal communication was managed by Model2gether. As an example of non-verbal communication, we picked the "point to" task, made by sighted

participants with a click in a model element. The test involved a set of modeling tasks with UML Use Case models.

11.2.1 Preparing the tests

In order to select the interfaces that would be used to evaluate alternatives in terms of information overload, we considered two main different scenarios that may take place. The first one involves continuous notifications (to test if people with blindness can concurrently scan information and update the model) and the second one involves no notifications. We decided to test two different levels of continuous notifications.

Seeking to make participants familiar with the tool, we invited them to conduct a preliminary use of the tool. For this, they were asked to carry out exactly the same activities asked at the first user test (chapter 9): (i) open the tool website and create an account; (ii) sign-in into the system; (iii) find the help menu, open and read it; (iv) open a Use Case model that was shared with them and read its content; and finally (v) make a change in the model.

In order to guarantee that the knowledge about the model would not influence the user study, the participants attended a lecture concerning concepts of Use Case modeling. The lecture was conducted using the synchronous communication service and Model2gether. The option "Follow Updates" was enabled for all participants with blindness so that every pointing and changing made by the sighted participant was instantaneously informed to them. The participants were allowed to make questions at any time. During the lecture, the Use Case model purpose and importance were discussed. After that, the Use Case model elements were presented in the following order: use case, actor, association, dependence (inclusion and extension), and inheritance. Each element, had its definition and role in the model discussed. Then, following the participants' suggestions, a Use Case model for a library system was created. After the lecture, participants had to answer the following questions about Use Case models to check their knowledge.

1. What is the purpose of Use Case models?
2. Define actors, use cases, and associations.

3. Is 'Database' a valid Library System actor?
4. Give three examples of actors in an e-Commerce system.
5. What is the difference between the inclusion and extension relationships?
6. What is the difference between the inheritance relationship established between actors and use cases?

The user test involved executing a set of activities, performed remotely. Communication between participants was provided by a synchronous communication service. As aforementioned, the activities were conducted in pairs of blind-sighted people. As only one sighted person participated, the sessions were scheduled individually with each participant with blindness.

Before starting the activities, the author gave an overview of what would be done. He explained that they would perform 3 modeling activities and, after that, they would have to answer questions related to each of them.

In order to perform the activities, each pair received 3 system descriptions to model using use cases (an academic system, a restaurant system, and an e-commerce system). The descriptions defined features so as to guarantee/ensure that the systems model size would not differ. Each model domain was explained to the partner. The features were divided (50/50) among the participants and each one had to create the actors, use cases, and relationships related to the features received. Some of the features overlapped in terms of actors and use cases in order to require participants' knowledge about what the other participant was doing (awareness).

In order to isolate the effects of awareness and non-verbal communication, each system was modeled with the same collaborative configuration (despite differences in awareness and non-verbal communication). Additionally, to assure that the order in which each awareness and non-verbal communication configuration was used did not influence the results, we varied the order for the users.

One of the systems was modeled without continuous information (A). The participants with blindness were instructed to disable the checkbox "Follow model updates" and to turn it on only when they felt necessary.

Another one was modeled only with beep to inform that something changed or an element was selected (B). That is to say, no messages were continuously communicated about changes. Only a beep sound was reproduced when the other participant made changes to the model. In order to be aware of changes, the participant with blindness could navigate through the history of actions made by the other participant.

Finally, the last system was modeled with continuous awareness and pointing information (C). In other words, every change made to the model by one participant and every pointing was immediately communicated by the system to the other in the pair by messages, such as "A new actor was created: Student".

In Table 38, we show the order in which each pair executed the activity.

Table 38: Activity configuration for each pair

Pair	Order of Modeling		
	1st	2nd	3rd
1	Academic (A)	Restaurant (B)	E-Com. (C)
2	Restaurant (B)	Academic (C)	E-Com. (A)
3	E-Com. (C)	Restaurant (A)	Academic (B)
4	Academic (B)	E-com. (A)	Restaurant (C)

Pairs were allowed to communicate via the communication service in all the three activities. All the users used a screen recording software to record their activity and the conversation was also recorded with their consent.

After the tests, the participants answered the following questionnaire about the tool and the activities.

1. What difficulties did you face during the activities?
2. Were you able to track what your partner was doing?
3. Which of the three scenarios did you prefer? Why?
4. Do you have any suggestions to improve the tool?

The lecture conducted in the preparation phase was the very first contact of the participants with blindness with the awareness mechanisms. It took about 40 minutes to finish. The participants were able to follow the highlights and changes made by the

instructor during the activities and to explore the highlighted elements. The only interruptions made during the activities were related to questions about Use Case concepts and were very similar to those that happen in a traditional object-oriented modeling lecture. The participants performance on the post-activity questions was excellent and all of them responded most of the questions correctly. The remaining doubts were discussed and solved. Participants with blindness were very excited about the lecture. Participant 1 commented "It was the first time I felt comfortable following a class/lesson that contains graphical content".

Table 39 shows how long it took for each pair to finish each activity.

Table 39: Activity duration by pair

	How long the activity took		
	1st	2nd	3rd
Pair 1 (#1 and #5)	7'12"	6'38"	10'37"
Pair 2 (#2 and #5)	6'2"	11'10"	6'35"
Pair 3 (#3 and #5)	10'56"	5'54"	5'51"
Pair 4 (#4 and #5)	7'33"	7'56"	9'37"

Concerning the test in pairs, at the beginning of the activities with continuous awareness (C), all participants with blindness commented that it was very challenging to make changes to the model and to think while they were receiving messages about what the other user was doing. During the video recording review, we checked that some of them stopped making changes and waited for a silent period to start working with the model.

With respect to the activity without awareness information (A), participants with blindness did not find it challenging to concentrate and make changes in the model. However, we checked that they turned on and off the awareness many times to check if the other user had made changes. Some of them tried to ask if changes were made using the communication service, but both participants found it difficult to identify from what point in the past the modifications should be informed.

In the activity with beep sounds (B), the users reduced the time between turning on and off their awareness, since they were informed about changes made to the model by a beep sound. Then, they could navigate through the history of the coworker's actions. Among the three activities, there was a consensus that this was the best scenario in

terms of awareness and concentration. However, even with the beep sounds, when the sighted participant created parts of the model in a faster way, two of the participants with blindness complained that the beep sounds sometimes interfered with their attention to the activity they were performing.

The activities duration decreased from C to A and from A to B independently of the pair. Analyzing the recordings, it is possible to say that there was no change in the rhythm participants with blindness were adopting when using the tool. Hence, the duration of the activities was not related to the user's attitude while interacting with the system. The differences are due to the inactive periods in the first activity (waiting for the sighted user to stop working) and to the frequent turning on and off the awareness box in the second activity.

Table 40 shows part of the participants' answers for the post-activities questionnaire (questions 1 to 3).

Regarding question 4, participant 4 commented that filtering messages from specific users would help in a scenario with more than 2 participants. Participant 2 gave two suggestions regarding awareness in general. The first one relates to the possibility of not being beeped when the model changes, but that the DSL representation of the model was updated whenever a change was made to the model. Thus, he could use the history of actions together with a real-time representation of the model.

Participants suggested that groupware could implement configurable levels of awareness and communication. This way, a user would be able to define what type of information each level should convey. Shortcuts could be used in order to allow the user to change between these levels during a collaborative activity.

By applying Collab4All, we noticed that the method can orient the identification of aspects that must be addressed in an inclusion scenario that had not been addressed by other authors.

Threats to Validity

There were some threats to the validity of the tests we conducted. For instance, the focus was on only one task and there was a unique iteration in the tests. We understand

Table 40: Answers of blind individuals to questions 1 to 3.

Blind	Question		
	1	2	3
1	I just could carry on any modeling while I was receiving feedback from what the sighted participant was doing in the model...	Yes, but it bothered me during the first activity.	The third was the best for me, but only the beep sound was not enough. The navigation through the history of actions was essential for me together with the beep.
2	This continuous awareness feature did not allow me to work at the same time the sighted participant was working. And I tried hard...The beep helped a lot, but when you made repeated changes to the model, the beeps bothered me.	Sure. In the first activity, I was completely aware of what the sighted participant was doing, but I could not work at the same time. In the second activity, I lost some of my awareness, but I was checking sometimes if the sighted participant was doing any changes to the model.	The beep scenario, but I have suggestions to improve that.
3	The system is really interesting. OK! It is perfect for presentations.	In all the three activities. The best one for me was the third one because I was informed about changes and I could navigate through the history of actions to check what you were doing.	The beep activity.
4	I faced some initial difficulties opening the tool, but after the lesson and specifying port 6223, everything was OK. The tool is great. The first activity was a little bit difficult, but I waited for the sighted participant to finish her part and finished mine. The second one was better, but not receiving any feedback about what the sighted participant was doing was also bad. The beep took my attention sometimes and I had to take some seconds to concentrate again.	Yes, the tool did a great job regarding that.	The last one.

that further tests and experiments are required. Nonetheless, we considered that some sort of validation would be a valuable contribution to those in the field and could server as a basis for future work.

Considerations

Having proposed Collab4All, it was necessary to conduct a proof of concept with the aim of verifying that it has practical potential. In order to do that, we focused on two issues identified by Collab4All regarding Model2gether: the "point to" task and information overload. Based on the findings, we changed Model2gether and conducted a user study to test this new version. Participants reported that information overload was indeed an issue and they were able to manage information overload with one awareness alternative implemented in Model2gether.

A panorama of Collab4All was published in (LUQUE; BRANDÃO; BRANDÃO, 2017) and a paper detailing the method is being prepared for submission to a scientific journal.

In the next part we will present our conclusions and opportunity for future work.

PART IV

FINAL CONSIDERATIONS

Part IV is the last of this document. It presents a discussion about the results achieved followed by some conclusions. Hence, we give some suggestions of future work to be carried in several levels: as initial research work, as master theme and as PhD theme. Finally, we list all the publications yielded from this thesis.

12 DISCUSSIONS AND CONCLUSIONS

The focus of this thesis was initially to address the inclusion of individuals with blindness in UML diagram-based collaborative activities. While we were addressing this challenge, we realized that there was a gap regarding methods to support (re)designing of groupware when considering the inclusion of individuals with impairments. This way, we shifted the thesis focus to the definition of a method that could support such activity. As a result, we defined Collab4All and analyzed its viability through a proof of concept in a diagram-based collaborative scenario.

Revisiting the thesis objectives, we can say that we were able to reach the established general and specific objectives.

We have contributed to the research on the inclusion of individuals with blindness in diagram-based collaborative activities. After reviewing the related literature and existing tools, we defined requirements to support such activities. These requirements were then implemented in Model2gether, a free web-based groupware that supports inclusive and collaborative modeling of UML use case diagrams. In comparison of existing tools, Model2gether supports real-time interaction involving both sighted individuals and individuals with blindness. Moreover, it implements a non-verbal communication feature - "point to" elements -, relevant in various scenarios of diagram-based activities. These features have not been found together in existing tools. We evaluated Model2gether through user tests and results indicated that it can be used to conduct collaborative lectures and group activities. The participants' feedback showed that individuals with blindness were able to learn as much as sighted learners using Model2gether. In addition of being able to be used by other researchers in this area, Model2gether's architecture and design facilitate implementing new diagrams and adding new features.

We also contributed to the field of CSCW in general by defining Collab4All, a new method to support (re)designing groupware when considering individuals with impairments. The method rationale involves establishing dependencies between tasks requirements, MHP components, and individuals impairments and disabilities, in order to

identify potential challenges and alternative solutions that may arise in CSCW involving individuals with impairments. While the method has been defined with groupware (re)design in mind, it can also be applied to the identification of aspects that must be addressed when studying the inclusion of individuals with impairments in CSCW. Therefore, we consider the contribution given with Collab4All surpass what it was proposed for.

The method viability was analyzed through a proof of concept in a diagram-based collaborative scenario. We used it to analyze a collaborative and remote activity related to editing UML use case diagrams using Model2gether. This analysis guided a redesign of Model2gether. The new version tool was then assessed through user tests and the results showed that individuals with blindness were able to work in pairs with sighted individuals.

Based on these results, we can affirm that the research hypothesis was confirmed. It is exactly the basis of Collab4All.

In summary, this thesis have both technological - Model2gether and its requirements - and scientific contributions - Collab4All and a strategy to manage information overload in CSCW involving individuals with blindness.

12.1 Future work opportunities

In this section, we give some suggestions of future work to be carried in several levels: as initial research work, as master theme and as PhD theme.

As undergraduate capstone projects, there are various technological opportunities related to the evolution of Model2gether:

- Implement new computing and engineering diagrams;
- Define new DSL for diagram specification;
- Implement new diagram representation strategies (e.g. hierarchical representations);
- Implement new forms of conveying non-verbal communication and awareness information to individuals with blindness (e.g. configurable levels, musical tones);

- Integrate Model2gether with existing CASE tools by implementing plugins to these tools.

As research themes for master's degree, we see both technological and scientific contributions that can be made:

- Define an architecture and an associate communication protocol to support the integration between Model2gether and existing CASE tools;
- Define and create a knowledge base for Collab4All related to challenges commonly faced when considering the inclusion of individuals with different types of impairments in CSCW. This knowledge base could be used as a Collab4All input artifact in the "Analyze Potential Challenges" activity. It would be of great help to researchers and developers who are starting working with the inclusion of individuals with impairments in CSCW;
- Analyze what are the best representation for specific types of diagrams when considering the inclusion of individuals with blindness in diagram-based collaborative activities;
- Define and validate multimodal interfaces, including tactile feedback, to convey non-verbal communication and awareness information to individuals with blindness in diagram-based collaborative activities.

Finally, the following can be explored as research themes for doctorate degree:

- Define and validate metrics and strategies to evaluate the quality of answers to Collab4All questions in order to optimize the method results;
- Evaluate how other human processing models can contribute to the method structure.

12.2 Publications

Next, we present a list of achievements related to this thesis, including awards and published papers:

- 2017-2018:

- (LUQUE et al., 2018): Luque, L. ; Brandão, L.O. ; Kira, E. ; A. F. Brandão, Anarosa . On the inclusion of learners with visual impairment in computing education programs in Brazil: practices of educators and perceptions of visually impaired learners. JOURNAL OF THE BRAZILIAN COMPUTER SOCIETY, v. 24, p. 1-12, 2018.
<https://link.springer.com/article/10.1186/s13173-018-0068-0>
- (LUQUE; BRANDÃO; BRANDÃO, 2018): Luque, L. ; Brandão, L.O. ; A. F. Brandão, Anarosa . What Is Missing in Web_Based Textual UML Tools to Allow the Inclusion of Blind People in Academia and Industry?. JOURNAL OF CONVERGENCE INFORMATION TECHNOLOGY (GYEONGJU), v. 13, p. 33-46, 2018.
<http://www.globalcis.org/dl/citation.html?id=JCIT-4402>
- (LUQUE et al., 2018): Luque, L. ; Brandão, L.O. ; Brandao, Anarosa Alves Franco . A Framework to Foster Diversity in Collaborative Activities. In: Frontiers in Education Conference, 2018, San Jose. 2018 CONFERENCE PROCEEDINGS. Piscataway: IEEE, 2018. v. 1. p. 1-9. (pending publication at IEEEExplore);
- (LUQUE et al., 2017) LUQUE, LEANDRO ; DE OLIVEIRA BRANDAO, LEONIDAS ; KIRA, ELISABETI ; ALVES, ANAROSA ; BRANDAO, FRANCO . Inclusion in computing and engineering education: Perceptions and learning in diagram-based e-learning classes with blind and sighted learners. In: 2017 IEEE Frontiers in Education Conference (FIE), 2017, Indianapolis. 2017 IEEE Frontiers in Education Conference (FIE), 2017. v. 1. p. 1-8.
<http://ieeexplore.ieee.org/abstract/document/8190513/>;
- (LUQUE; BRANDÃO; BRANDÃO, 2017): LUQUE, LEANDRO; BRANDÃO, LEÔNIDAS DE OLIVEIRA ; BRANDÃO, ANAROSA ALVES FRANCO . Proposal and validation of a method for the inclusion of blind people in cooperative modelling activities. ACM SIGACCESS Accessibility and Computing, New York, p. 30 - 34, 01 jun. 2017.
<https://dl.acm.org/citation.cfm?id=3051526>;

- 2016:

- Awarded with the Google Research Award for Latin America - LARA;

- (LUQUE et al., 2016) Luque, L. ; SANTOS, C. L. F. ; CRUZ, D. O. ; BRANDAO, LEONIDAS O. ; Brandão, Anarosa A. F. . Model2gether: a tool to support cooperative modeling involving blind people. In: VII CONGRESSO BRASILEIRO DE SOFTWARE: TEORIA E PRATICA (CBSOFT 2016): SESSAO DE FERRAMENTAS, 2016, Maringa. ANAIS/Proceedings. Porto Alegre: SBC, 2016. v. 1. p. 73-80. :

* Awarded with Honored Mention;

* <https://drive.google.com/open?id=0B835uEP7FyHbE5CdkI5d1lrM0U;>

- (LUQUE; BRANDÃO; BRANDÃO, 2016): Luque, L. ; SANTOS, C. L. F. ; CRUZ, D. O. ; Brandão, L.O. ; BRANDAO, ANAROSA ALVES FRANCO . Model2gether: uma ferramenta de apoio ao ensino e a aprendizagem de modelos por cegos. In: Congresso Brasileiro de Informatica na Educacao - CBIE 2016 - Apps.edu, 2016, Uberlandia. Anais do V Congresso Brasileiro de Informatica na Educacao. Uberlandia: UFU, 2016. v. 1. p. 1-8.

<http://www.br-ie.org/pub/index.php/wcbie/article/download/6936/4810;>

* Awarded as Best Prototype of Apps.edu@CBIE2016

<https://drive.google.com/open?id=0B835uEP7FyHUUJpOWhnRHVDtKE>

- 2014-2015:

- (LUQUE et al., 2015b): Luque, L. ; BRANDAO, LEONIDAS O. ; TORI, R. ; Brandao, Anarosa A. F. . On the Inclusion of Blind People in UML e-Learning Activities. Revista Brasileira de Informatica na Educacao, v. 23, p. 18, 2015.

<http://www.br-ie.org/pub/index.php/rbie/article/view/3314;>

- (LUQUE et al., 2014): LUQUE, LEANDRO ; O. BRANDÃO, LEONIDAS ; TORI, ROMERO ; A. F. Brandão, Anarosa . Are You Seeing This? What Is Available and How Can We Include Blind Students in Virtual UML Learning Activities. In: XXV Simposio Brasileiro de Informatica na Educacao, 2014, Dourados, 2014. v. 1. p. 204-213.

* Awarded as best paper at CBIE 2014

<http://www.br-ie.org/pub/index.php/sbie/article/view/2946;>

REFERENCES

- ABNER, G.; LAHM, E. Implementation of assistive technology with students who are visually impaired: teachers' readiness. **Journal of Visual Impairment & Blindness**, AFB Press, American Foundation for the Blind, v. 96, n. 02, 2002.
- ACHECKER. 2018. Disponível em: <<https://achecker.ca/checker/index.php>>. Acesso em: 15 Nov. 2018.
- ALBINO, I. B. **Acesso e permanência na Universidade Federal do Rio Grande do Norte sob o ponto de vista do docente e do estudante com deficiência [In Portuguese]**. Dissertação (Master's thesis) — Universidade Federal do Rio Grande do Norte, Natal, 2010.
- ALVES, C. C. d. F. et al. Assistive technology applied to education of students with visual impairment. **Revista Panamericana de Salud Pública**, SciELO Public Health, v. 26, p. 148–152, 2009.
- AMIRALIAN, M. L. T. M. O psicólogo e as pessoas com deficiência visual [In Portuguese]. In: MASINI, E. F. S. (Ed.). **Do sentido, pelos sentidos, para o sentido: sentidos das pessoas com deficiência sensorial**. São Paulo: Vetor Editora Pedagógica, 2002. p. 201–208.
- ANGKANANON, K.; WALD, M.; GILBERT, L. Technology enhanced interaction framework and method for accessibility in Thai museums. In: **Proceedings of the 3rd International Conference on Information and Communication Technology (ICoICT)**. Nusa Dua, Bali: [s.n.], 2015. p. 316–321.
- ANTIA, S. D. et al. Social outcomes of students who are deaf and hard of hearing in general education classrooms. **Exceptional Children**, SAGE Publications Sage CA: Los Angeles, CA, v. 77, n. 4, p. 489–504, 2011.
- ARENA, P. et al. Generation of n-double scrolls via cellular neural networks. **International Journal of circuit theory and applications**, Wiley Online Library, v. 24, n. 3, p. 241–252, 1996.
- ASSIMAKOPOULOS, N. A. Information and decision support systems as a challenge for new democracies. In: **Diffusion of New Technologies in the Post-Communist World**. Netherlands: Springer, 1997. v. 13, p. 161–174.
- BADDELEY, A. Working memory. **Science**, American Association for the Advancement of Science, v. 255, n. 5044, p. 556–559, 1992.
- BADDELEY, A. D. The development of the concept of working memory: Implications and contributions of neuropsychology. In: **Neuropsychological impairments of short-term memory**. New York, NY, US: Cambridge University Press, 1990. p. 54–73. ISBN 0-521-37088-4 (Hardcover).

- BAGATELL, N. et al. Effectiveness of therapy ball chairs on classroom participation in children with autism spectrum disorders. **American Journal of Occupational Therapy**, American Occupational Therapy Association, v. 64, n. 6, p. 895–903, 2010.
- BALIK, S. M. et al. **Combinatorial Graph Creation and Navigation for Blind People**. Tese (Doutorado) — North Carolina State University, 2014.
- BANNON, L. J.; SCHMIDT, K. CSCW-four characters in search of a context. **DAIMI Report Series**, v. 18, n. 289, 1989.
- BARAK, M. E. M. **Managing diversity: toward a globally inclusive workplace**. 4. ed. USA: Sage Publications, 2016.
- BARBOSA, S.; SILVA, B. **Interação Humano-Computador [In Portuguese]**. Rio de Janeiro: Elsevier Brasil, 2010.
- BARRETO, F. C.; DEUS, L. C. J. de; APOLONIO, S. de O. Collaborative writing as a mechanism of interaction among hearing impaired and listeners. In: **Proceedings of the II Brazilian Symposium of Collaborative Systems**. Belo Horizonte: [s.n.], 2010. p. 32–35.
- BECK, K. Embracing change with extreme programming. **Computer**, IEEE, v. 32, n. 10, p. 70–77, 1999.
- BIENTZLE, M. et al. Enhancing pair learning of pupils with cognitive disabilities: Structural support with help of floor control. In: INTERNATIONAL SOCIETY OF THE LEARNING SCIENCES. **Proceedings of the 9th international conference on Computer supported collaborative learning-Volume 1**. [S.l.], 2009. p. 517–521.
- BLENKHORN, P.; EVANS, D. G. Using speech and touch to enable blind people to access schematic diagrams. **Journal of Network and Computer Applications**, Elsevier, v. 21, n. 1, p. 17–29, 1998.
- BOEHM, B. W. A spiral model of software development and enhancement. **Computer**, IEEE, v. 21, n. 5, p. 61–72, 1988.
- BOOCH, G. The booch method: process and pragmatics. In: SIGS PUBLICATIONS, INC. **Object development methods**. UK, 1994. p. 149–166.
- BOOCH, G.; RUMBAUGH, J.; JACOBSON, I. **UML: guia do usuário (In Portuguese)**. [S.l.]: Elsevier Brasil, 2006.
- BORGHOFF, U. M.; SCHLICHTER, J. H. Computer-supported cooperative work. In: **Computer-Supported Cooperative Work**. [S.l.]: Springer, 2000. p. 87–141.
- BORODIN, Y. et al. More than meets the eye: a survey of screen-reader browsing strategies. In: ACM. **Proceedings of the 2010 International Cross Disciplinary Conference on Web Accessibility (W4A)**. [S.l.], 2010. p. 13.
- BRAZIL. **eMAG, Acessibilidade de Governo Eletrônico–Cartilha Técnica [In Portuguese]**. 2011. Disponível em: <<http://emag.governoeletronico.gov.br/>>. Acesso em: 15 Nov. 2018.

Brazil. **Lei 13.146 de 6 de julho 2015 - Estatuto das Pessoas com Deficiência [In Portuguese]**. 2018. Disponível em: <www.planalto.gov.br/ccivil_03/_ato2015-2018/2015/lei/l13146.htm>. Acesso em: 15 Nov. 2018.

_____. **Lei 9.394, de 20 de dezembro de 1996 - Lei de Diretrizes e Bases da Educação Nacional (LDB) [In Portuguese]**. 2018. Disponível em: <www.planalto.gov.br/ccivil_03/leis/L9394.htm>. Acesso em: 15 Nov. 2018.

_____. **Portaria 1.679 de 2 de dezembro de 1999 [In Portuguese]**. 2018. Disponível em: <http://portal.mec.gov.br/sesu/arquivos/pdf/c1_1679.pdf>. Acesso em: 15 Nov. 2018.

BRERETON, P. et al. Lessons from applying the systematic literature review process within the software engineering domain. **Journal of systems and software**, Elsevier, v. 80, n. 4, p. 571–583, 2007.

BREWER, R. N.; PIPER, A. M. xpress: Rethinking design for aging and accessibility through a voice-based online blogging community. **PACM HCI**, v. 1, n. 2, 2017.

BROOKSHIRE, R. G. Teaching UML database modeling to visually impaired students. **Issues in Information Systems**, v. 7, n. 1, p. 98–101, 2006.

BROWN, A.; STEVENS, R.; PETTIFER, S. Issues in the non-visual presentation of graph based diagrams. In: IEEE. **Information Visualisation, 2004. IV 2004. Proceedings. Eighth International Conference on**. [S.l.], 2004. p. 671–676.

BURKHAUSER, R. V.; DALY, M. **The declining work and welfare of people with disabilities: what went wrong and a strategy for change**. [S.l.]: AEI Press, 2011.

BUZAN, T.; BUZAN, B. **Mind Map Book**, 1/e. [S.l.]: Rajpal & Sons, 2010.

BUZZI, M. C. et al. Accessing google docs via screen reader. In: MIESENBERGER, K. et al. (Ed.). **Computers Helping People with Special Needs**. [S.l.]: Springer, 2010. p. 92–99.

CALDER, M. et al. Plumb:: an interface for users who are blind to display, create, and modify graphs. In: ACM. **Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility**. [S.l.], 2006. p. 263–264.

CALVARY, G.; COUTAZ, J.; NIGAY, L. From single-user architectural design to pac*: a generic software architecture model for cscw. In: ACM. **Proceedings of the ACM SIGCHI Conference on Human factors in computing systems**. [S.l.], 1997. p. 242–249.

CAPOVILLA, D.; MÜHLING, A.; HUBWIESER, P. How learning styles in CS can foster inclusion of visually impaired students. In: IEEE. **Proceedings of the 2015 International Conference on Learning and Teaching in Computing and Engineering (LaTiCE)**. [S.l.], 2015. p. 187–192.

CARD, S. K. **The psychology of human-computer interaction**. [S.l.]: CRC Press, 2017.

CARMEN, S. et al. Increasing workplace independence for people with cognitive disabilities by leveraging distributed cognition among caregivers and clients. In: ACM. **Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work**. [S.l.], 2003. p. 95–104.

CERUZZI, P. E. et al. **A history of modern computing**. [S.l.]: MIT press, 2003.

CHAHINI, T. H. C. **Os desafios do acesso e da permanência de pessoas com necessidades especiais nas instituições de educação superior de São Luís [In Portuguese]**. Dissertação (Master's thesis) — Universidade Federal do Maranhão, São Luís, 2005.

CHANG, Y.-J.; LIU, H.-H.; WANG, T.-Y. Mobile social networks as quality of life technology for people with severe mental illness. **IEEE Wireless Communications**, IEEE, v. 16, n. 3, 2009.

CHARLES, P. K. et al. A review on the various techniques used for optical character recognition. **International Journal of Engineering Research and Applications**, Citeseer, v. 2, n. 1, p. 659–662, 2012.

CHEN, P. P.-S. Applications of the entity-relationship model. In: **Data Base Design Techniques I**. [S.l.]: Springer, 1982. p. 87–113.

CHIA, N. K. H.; KEE, N. K. N. Harnessing ipad for lesson study within the triple-d framework in special education. In: SINGAPORE THERAPEUTIC, ASSISTIVE & REHABILITATIVE TECHNOLOGIES (START) CENTRE. **Proceedings of the 6th International Conference on Rehabilitation Engineering & Assistive Technology**. [S.l.], 2012. p. 23.

CHRISTOPHER, D. W. **Engineering Psychology and Human Performance**. [S.l.]: Merrill, 1984.

COBURN, S.; OWEN, C. B. UML diagrams for blind programmers. In: **Proceedings of the 2014 ASEE North Central Section Conference**. [S.l.: s.n.], 2014.

COHEN, R. F. et al. Using an audio interface to assist users who are visually impaired with steering tasks. In: ACM. **Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility**. [S.l.], 2006. p. 119–124.

COHEN, R. F.; MEACHAM, A.; SKAFF, J. Teaching graphs to visually impaired students using an active auditory interface. In: ACM. **ACM SIGCSE Bulletin**. [S.l.], 2006. v. 38, n. 1, p. 279–282.

COHEN, R. F. et al. Plumb: displaying graphs to the blind using an active auditory interface. In: ACM. **Proceedings of the 7th international ACM SIGACCESS conference on Computers and accessibility**. [S.l.], 2005. p. 182–183.

COLE, M. **Education, equality and human rights: issues of gender, race, sexuality, disability and social class**. [S.l.]: Routledge, 2017.

CONNELLY, R. Lessons and tools from teaching a blind student. **Journal of Computing Sciences in Colleges**, Consortium for Computing Sciences in Colleges, v. 25, n. 6, p. 34–39, 2010.

CONSORTIUM, I. G. L. et al. Ims guidelines for developing accessible learning applications. **Retrieved October**, v. 20, p. 2004, 2002.

CONSORTIUM, W. W. W. et al. Web content accessibility guidelines (WCAG) 2.0. World Wide Web Consortium, 2008.

COSQUER, F. J. et al. Support for distributed cscw applications. In: **Advances in Distributed Systems**. [S.l.]: Springer, 2000. p. 295–326.

CRUZ, A. et al. Towards an overarching classification model of cscw and groupware: a socio-technical perspective. In: SPRINGER. **International Conference on Collaboration and Technology**. [S.l.], 2012. p. 41–56.

CRUZ, R. L. **Inclusão no ensino superior: um estudo das representações sociais dos acadêmicos com deficiência visual da UFPB [In Portuguese]**. Dissertação (Master's thesis) — Universidade Federal da Paraíba, João Pessoa, 2012.

CRYSTAL, A.; ELLINGTON, B. Task analysis and human-computer interaction: approaches, techniques, and levels of analysis. **AMCIS 2004 Proceedings**, p. 391, 2004.

DELL, A. G.; NEWTON, D. A.; PETROFF, J. G. **Assistive technology in the classroom: Enhancing the school experiences of students with disabilities**. 3. ed. [S.l.]: Pearson, 2016.

DING, X.; SHIH, P. C.; GU, N. Socially embedded work: A study of wheelchair users performing online crowd work in china. In: ACM. **Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing**. [S.l.], 2017. p. 642–654.

DISABILITY Resource Center - University of Kentucky. 2018. Disponível em: <https://www.uky.edu/DisabilityResourceCenter/>. Acesso em: 15 Nov. 2018.

DISABILITY Resource Center - University of Reno. 2018. Disponível em: <http://www.unr.edu/drc>. Acesso em: 15 Nov. 2018.

DISABILITY Resource Centre - University of Cambridge. 2018. Accessed January 16, 2018. Disponível em: <http://www.disability.admin.cam.ac.uk/>.

DOBING, B.; PARSONS, J. How uml is used. **Communications of the ACM**, ACM, v. 49, n. 5, p. 109–113, 2006.

DOCS, G. 2015. Disponível em: <https://docs.google.com>. Acesso em: 15 Nov. 2018.

DOUGLAS, G. Ict, education, and visual impairment. **British Journal of Educational Technology**, Wiley Online Library, v. 32, n. 3, p. 353–364, 2001.

DYKE, J. A. V. The role of memory in language and communication. In: **Cognition and acquired language disorders**. [S.l.]: Elsevier, 2012. p. 94–120.

EDUCATION, T. H. **Times Higher Education Universities Ranking**. 2018. Disponível em: <https://www.timeshighereducation.com/>. Acesso em: 15 Nov. 2018.

EDWARDS, B. J.; LEWIS, S. The use of technology in programs for students with visual impairments in florida. **Journal of Visual Impairment & Blindness**, ERIC, v. 92, n. 5, p. 302–12, 1998.

EIDE, A.; INGSTAD, B. **Disability and poverty: a global challenge**. [S.l.]: Policy Press, 2017.

ELLIS, C. A.; GIBBS, S. J.; REIN, G. Groupware: some issues and experiences. **Communications of the ACM**, ACM, v. 34, n. 1, p. 39–58, 1991.

ESERYEL, D.; GANESAN, R.; EDMONDS, G. S. Review of computer-supported collaborative work systems. **Educational Technology & Society**, JSTOR, v. 5, n. 2, p. 130–136, 2002.

FERNANDEZ, F.; ROA, L.; CHÁVEZ, F. Telecommunication system for handicapped people. In: IEEE. **Information Technology Applications in Biomedicine, 2000. Proceedings. 2000 IEEE EMBS International Conference on**. [S.l.], 2000. p. 324–328.

FICHTEN, C. S. et al. Accessibility of e-learning and computer and information technologies for students with visual impairments in postsecondary education. **Journal of Visual Impairment & Blindness**, American Foundation for the Blind, v. 103, n. 9, p. 543–557, 2009.

FITZPATRICK, D.; MCMULLEN, D. Distance learning of graphically intensive material for visually impaired students. In: SPRINGER. **International Conference on Computers for Handicapped Persons**. [S.l.], 2008. p. 219–225.

FÖDISCH, M.; CROMBIE, D.; IOANNIDIS, G. Tedub: Providing access to technical drawings for print impaired people. In: CITESEER. **Proceedings of Conference and Workshop on Assistive Technologies for Vision and Hearing Impairment: Accessibility, Mobility and Social Integration**. [S.l.], 2002.

FORUM, G. **Cegos Programadores [In Portuguese]**. 2018. Accessed January 16, 2018.

FOWLER, M.; PARSONS, R. **Domain-Specific Languages**. [S.l.]: Addison-Wesley, 2010.

FRANCO, M. A. C. Acesso à universidade: uma questão política e um problema metodológico [In Portuguese]. **Educação e Seleção**, n. 12, p. 9–26, 2013.

FRASER, W. J.; MAGUVHE, M. O. Teaching life sciences to blind and visually impaired learners. **Journal of Biological Education**, Taylor & Francis, v. 42, n. 2, p. 84–89, 2008.

FUKS, H. et al. Applying the 3c model to groupware development. **International Journal of Cooperative Information Systems**, World Scientific, v. 14, n. 02n03, p. 299–328, 2005.

GADELHA, B. et al. An approach for developing groupware product lines based on the 3c collaboration model. In: SPRINGER. **International Conference on Collaboration and Technology**. [S.l.], 2009. p. 328–343.

GAMMA, E. et al. Elements of reusable object-oriented software. **Reading: Addison-Wesley**, 1995.

GEROSA, M. A. et al. Development of groupware based on the 3c collaboration model and component technology. In: SPRINGER. **International Conference on Collaboration and Technology**. [S.l.], 2006. p. 302–309.

GILKES, A. M.; COWENS, M. W.; TAYLOR, L. A. **Electronic refreshable tactile display for Braille text and graphics**. [S.l.]: Google Patents, 1996. US Patent 5,580,251.

GREENBERG, S. Computer-supported cooperative work and groupware: an introduction to the special issues. **International Journal of Man-Machine Studies**, Elsevier, v. 34, n. 2, p. 133–141, 1991.

_____. Personalizable groupware: Accommodating individual roles and group differences. In: SPRINGER. **Proceedings of the Second European Conference on Computer-Supported Cooperative Work ECSCW'91**. [S.l.], 1991. p. 17–31.

GRILLO, F. D. N.; FORTES, R. P. de M. Accessible modeling on the web: a case study. **Procedia Computer Science**, Elsevier, v. 27, p. 460–470, 2014.

_____. Tests with blind programmers using awmo: An accessible web modeling tool. In: SPRINGER. **International Conference on Universal Access in Human-Computer Interaction**. [S.l.], 2014. p. 104–113.

GRILLO, F. D. N.; FORTES, R. P. de M.; LUCRÉDIO, D. Towards collaboration between sighted and visually impaired developers in the context of model-driven engineering. In: **Joint Proceedings of Co-located Events at the 8th European Conference on Modelling Foundations and Applications (ECMFA 2012)**, Lyngby. [S.l.: s.n.], 2012. p. 241–251.

GUERREIRO, E. M. B. R.; ALMEIDA, M. A.; FILHO, J. H. da S. Avaliação da satisfação do aluno com deficiência no ensino superior [In Portuguese]. **Avaliação: Revista da Avaliação da Educação Superior**, SciELO Brasil, v. 19, n. 1, 2013.

GUTWIN, C.; GREENBERG, S. The effects of workspace awareness support on the usability of real-time distributed groupware. **ACM Transactions on Computer-Human Interaction (TOCHI)**, ACM, v. 6, n. 3, p. 243–281, 1999.

HAILPERN, J. et al. Aces: a cross-discipline platform and method for communication and language research. In: ACM. **Proceedings of the 2013 conference on Computer supported cooperative work**. [S.l.], 2013. p. 515–526.

HAMALAINEN, M. et al. User interface design principles for team support systems. In: IEEE. **System Sciences, 1991. Proceedings of the Twenty-Fourth Annual Hawaii International Conference on**. [S.l.], 1991. v. 3, p. 461–470.

HOFMAN, R. Behavioral economics in software quality engineering. **Empirical Software Engineering**, Springer, v. 16, n. 2, p. 278–293, 2011.

HORSTMANN, M. et al. Tedub: Automatic interpretation and presentation of technical diagrams for blind people. In: **Proceedings of Conference and Workshop on Assistive Technologies for Vision and Hearing Impairment-CVHI'2004, EURO-ASSIST-VHI-2: Accessibility, Mobility and Social Integration**. [S.l.: s.n.], 2004.

HUTCHINS, E. **Cognition in the Wild**. [S.l.]: MIT press, 1995.

IGLESIAS, R. et al. Computer graphics access for blind people through a haptic and audio virtual environment. In: IEEE. **Proceedings of the 3rd IEEE International Workshop on Haptic, Audio and Visual Environments and Their Applications**. [S.l.], 2004. p. 13–18.

ISO. **Systems and software engineering – Life cycle processes – Requirements engineering**. Geneva, CH, 2011.

_____. **Systems and software engineering - Systems and software Quality Requirements and Evaluation (SQuARE) - System and software quality models**. Geneva, CH, 2011.

IZAWA, C. **On human memory: Evolution, progress, and reflections on the 30th anniversary of the Atkinson-Shiffrin model**. [S.l.]: Psychology Press, 1999.

JACOBSON, I. **Object-oriented software engineering: a use case driven approach**. [S.l.]: Pearson Education India, 1993.

JACOBSON, I.; BOOCH, G.; RUMBAUGH, J. The unified process. **Ieee Software**, IEEE, n. 3, p. 96–102, 1999.

JATOBÁ, A. et al. Wiki for visual impaired people: Exploring new possibilities of collaboration. In: IEEE. **Sistemas Colaborativos (SBSC), 2009 Simposio Brasileiro de**. [S.l.], 2009. p. 202–209.

JAWS. 2018. Disponível em: <<https://www.freedomscientific.com/Products/Blindness/JAWS>>. Acesso em: 15 Nov. 2018.

JOHN, B. E.; KIERAS, D. E. The goms family of user interface analysis techniques: Comparison and contrast. **ACM Transactions on Computer-Human Interaction (TOCHI)**, ACM, v. 3, n. 4, p. 320–351, 1996.

JOHNSON-LENZ, P.; JOHNSON-LENZ, T. Groupware: coining and defining it. **ACM SIGGROUP Bulletin**, ACM, v. 19, n. 2, p. 34, 1998.

JS-SEQUENCE-DIAGRAMS. 2018. Disponível em: <<https://bramp.github.io/js-sequence-diagrams/>>. Acesso em: 15 Nov. 2018.

KANJO, E.; ASTHEIMER, P.; MARSHALL, I. Supporting face-to-face communications through interactive toys space. In: IEEE. **Information and Communication Technologies: From Theory to Applications, 2004. Proceedings. 2004 International Conference on**. [S.l.], 2004. p. 523–524.

KAPPERMAN, G.; STICKEN, J.; HEINZE, T. Survey of the use of assistive technology by illinois students who are visually impaired. **Journal of Visual Impairment & Blindness**, ERIC, v. 96, n. 2, p. 106–8, 2002.

KARDUCK, A. P. Seamless worlds for people with physical disabilities" teilhabe ohne anwesenheit". In: IEEE. **System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conference on**. [S.l.], 2000. p. 8–pp.

KARWOWSKI, W. Hierarchical task analysis. In: **International Encyclopedia of Ergonomics and Human Factors-3 Volume Set**. [S.l.]: CRC Press, 2006. p. 3231–3238.

KENNEL, A. R. Audiograf: a diagram-reader for the blind. In: ACM. **Proceedings of the second annual ACM conference on Assistive technologies**. [S.l.], 1996. p. 51–56.

KERBRAT, A.; ATALLAH, S. B. Formal specification of a framework for groupware development. In: **Formal Description Techniques VIII**. [S.l.]: Springer, 1995. p. 303–310.

KI, B.; KLASKY, S. Scivis. **Concurrency: Practice and Experience**, Wiley Online Library, v. 10, n. 11-13, p. 1107–1115, 1998.

KIENTZ, J. A. et al. From the war room to the living room: decision support for home-based therapy teams. In: ACM. **Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work**. [S.l.], 2006. p. 209–218.

KIM, J.-h.; HONG, K.-S. An extended cscw architecture using wearable personal station-based korean sign language recognizer. In: IEEE. **Computer Supported Cooperative Work in Design, 2006. CSCWD'06. 10th International Conference on**. [S.l.], 2006. p. 1–6.

KING, A. **Accessible UML Reference Manual**. 2011. Disponível em: <<http://access.uoa.gr/manuals/tedub/Accessible%20UML%20Manual.doc>>. Acesso em: 15 Nov. 2018.

_____. **Accessible UML**. 2018. Disponível em: <<http://www.alasdairking.me.uk/tedub/index.htm>>. Acesso em: 15 Nov. 2018.

KING, A. et al. Presenting UML Software Engineering Diagrams to Blind People. In: MIESENBERGER, K. et al. (Ed.). **Computers Helping People with Special Needs**. Springer Berlin Heidelberg, 2004, (Lecture Notes in Computer Science, 3118). p. 522–529. ISBN 978-3-540-22334-4 978-3-540-27817-7. DOI: 10.1007/978-3-540-27817-7_76. Disponível em: <http://link.springer.com/chapter/10.1007/978-3-540-27817-7_76>.

KING, A. R.; EVANS, D. S. **Re-presenting visual content for blind people**. [S.l.]: University of Manchester, 2007.

KITCHENHAM, B. Procedures for performing systematic reviews. **Keele, UK, Keele University**, v. 33, n. 2004, p. 1–26, 2004.

KUNZ, A. et al. Accessibility of brainstorming sessions for blind people. In: SPRINGER. **International Conference on Computers for Handicapped Persons**. [S.l.], 2014. p. 237–244.

LAKOV, D. V. Soft computing agent approach to remote learning of disabled. In: IEEE. **Intelligent Systems, 2004. Proceedings. 2004 2nd International IEEE Conference.** [S.l.], 2004. v. 1, p. 250–255.

LAURILLAU, Y.; NIGAY, L. Clover architecture for groupware. In: ACM. **Proceedings of the 2002 ACM conference on Computer supported cooperative work.** [S.l.], 2002. p. 236–245.

LI, B. E-learning with computer technology in handicapped higher education. In: IEEE. **E-Business and Information System Security, 2009. EBISS'09. International Conference on.** [S.l.], 2009. p. 1–4.

LINGNAU, A.; BIENTZLE, M. A technical framework to support implicit structured collaboration. In: INTERNATIONAL SOCIETY OF THE LEARNING SCIENCES. **Proceedings of the 9th international conference on Computer supported collaborative learning-Volume 1.** [S.l.], 2009. p. 527–531.

LIPPONEN, L.; HAKKARAINEN, K.; PAAVOLA, S. Practices and orientations of cscl. In: **What we know about CSCL.** [S.l.]: Springer, 2004. p. 31–50.

LIU, C.-C. et al. Constructing an mcscl groupware to improve the problem-solving experience of mathematics for hearing-impaired students. In: IEEE. **Advanced Learning Technologies, 2007. ICAIT 2007. Seventh IEEE International Conference on.** [S.l.], 2007. p. 345–347.

LIU, P.; DAI, G. Computer supported collaborative learning framework for the handicapped in ubiquitous computing environment. In: IEEE. **Networking, Sensing and Control, 2008. ICNSC 2008. IEEE International Conference on.** [S.l.], 2008. p. 1680–1682.

LIU, P.; DING, X.; GU, N. “helping others makes me happy”: Social interaction and integration of people with disabilities. In: ACM. **Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing.** [S.l.], 2016. p. 1596–1608.

LIU, Y.; FEYEN, R.; TSIMHONI, O. Queueing network-model human processor (qn-mhp): A computational architecture for multitask performance in human-machine systems. **ACM Transactions on Computer-Human Interaction (TOCHI)**, ACM, v. 13, n. 1, p. 37–70, 2006.

LOITSCH, C.; WEBER, G. Viable haptic uml for blind people. In: MIESENBERGER, K.; KARSHMERPETR, A.; ZAGLER, P. (Ed.). **Computers Helping People with Special Needs.** [S.l.]: Springer, 2012.

LOPRESTI, E. F.; MIHAILIDIS, A.; KIRSCH, N. Assistive technology for cognitive rehabilitation: State of the art. **Neuropsychological rehabilitation**, Taylor & Francis, v. 14, n. 1-2, p. 5–39, 2004.

LÖTZSCH, J. Computer-aided access to tactile graphics for the blind. In: ZAGLER, W.; BUSBY, G.; ROLAND, W. (Ed.). **Computers for Handicapped Persons.** Austria: Springer, 1994. p. 575–581.

LUQUE, L.; BRANDÃO, A. A. F.; BRANDÃO, L. de O. Proposal and validation of a method for the inclusion of blind people in cooperative modelling activities. **ACM SIGACCESS Accessibility and Computing**, ACM, n. 117, p. 30–34, 2017.

LUQUE, L. et al. Inclusion in computing and engineering education: Perceptions and learning in diagram-based e-learning classes with blind and sighted learners. In: IEEE. **2017 IEEE Frontiers in Education Conference (FIE)**. [S.l.], 2017. p. 1–8.

_____. Inclusion in computing and engineering education: Perceptions and learning in diagram-based e-learning classes with blind and sighted learners. In: IEEE. **2018 IEEE Frontiers in Education Conference (FIE)**. [S.l.], 2018.

_____. On the inclusion of blind people in UML e-learning activities. **Brazilian Journal of Informatics in Education**, v. 23, n. 02, p. 18, 2015.

_____. On the inclusion of blind people in UML e-learning activities. **Brazilian Journal of Informatics in Education**, v. 23, n. 02, p. 18, 2015.

LUQUE, L.; BRANDÃO, L. O.; BRANDÃO, A. A. F. Model2gether: uma ferramenta de apoio ao ensino e a aprendizagem de modelos por cegos. In: **Brazilian Conference of Informatics in Education**. [S.l.: s.n.], 2016. v. 5, n. 1, p. 257.

_____. What is missing in web-based textual uml tools to allow the inclusion of people who are blind in academia and industry? **Journal of Convergence Information Technology**, GlobalCIS, n. 13, p. 33–46, 2018.

LUQUE, L. et al. On the inclusion of learners with visual impairment in computing education programs in brazil: practices of educators and perceptions of visually impaired learners. **Journal of the Brazilian Computer Society**, v. 24, n. 1, p. 4, 2018.

_____. Are you seeing this? what is available and how can we include blind students in virtual uml learning activities. In: **Proceedings of The Brazilian Symposium on Computers in Education**. [S.l.: s.n.], 2014. v. 25, n. 1, p. 204–213.

_____. Model2gether: a tool to support cooperative modeling involving blind people. In: **Brazilian Conference of Software**. [S.l.: s.n.], 2016.

_____. Can We Work Together? On the Inclusion of Blind People in UML Model-Based Tasks. In: LANGDON, P. M. et al. (Ed.). **Inclusive Designing**. Springer International Publishing, 2014. p. 223–233. ISBN 978-3-319-05094-2 978-3-319-05095-9. DOI: 10.1007/978-3-319-05095-9_20. Disponível em: http://link.springer.com/chapter/10.1007/978-3-319-05095-9_20.

MACHADO, R. P.; CONFORTO, D.; SANTAROSA, L. Perception for cooperation: Case study in web text editors from the perspective of blind users. In: IEEE. **Computers in Education (SIIE), 2016 International Symposium on**. [S.l.], 2016. p. 1–6.

_____. Implementation of sound perception elements for visually impaired people in collaborative and synchronous web systems. In: ACM. **Proceedings of the XVI Brazilian Symposium on Human Factors in Computing Systems**. [S.l.], 2017. p. 62.

_____. Sound chat: Implementation of sound awareness elements for visually impaired users in web-based cooperative systems. In: IEEE. **Computers in Education (SIIIE), 2017 International Symposium on**. [S.l.], 2017. p. 1–6.

MAHLER, B. A. **Recovery of Language Skills in Chronic Severe Traumatic Brain Injury**. [S.l.]: Rush University, 2014.

MATHEW, A. R.; HAJJ, A. A.; ABRI, A. A. Human-computer interaction (hci): An overview. In: IEEE. **Computer Science and Automation Engineering (CSAE), 2011 IEEE International Conference on**. [S.l.], 2011. v. 1, p. 99–100.

MCGOOKIN, D.; BREWSTER, S.; BREWSTER, S. An initial investigation into non-visual computer supported collaboration. In: ACM. **CHI'07 Extended Abstracts on Human Factors in Computing Systems**. [S.l.], 2007. p. 2573–2578.

MCKINLAY, A. et al. Augmentative and alternative communication: The role of broadband telecommunications. **IEEE Transactions on Rehabilitation Engineering**, IEEE, v. 3, n. 3, p. 254–260, 1995.

MCMULLEN, D.; FITZPATRICK, D. Autonomous access to graphics for visually impaired learners. **Irish Educational Technology User's**, 2009.

MEC. **Sistemas eletrônico do Ministério da Cultura e Educação [In Portuguese]**. 2017. Disponível em: <<http://emec.mec.gov.br/emec/nova>>. Acesso em: 15 Nov. 2018.

MEC - Ministério da Educação. **Projeto Livros Acessíveis [In Portuguese]**. 2018. Disponível em: <<http://www.uol.com.br>>. Acesso em: 15 Nov. 2018.

MEDEIROS, D. et al. A case study on the implementation of the 3c collaboration model in virtual environments. In: IEEE. **Virtual and Augmented Reality (SVR), 2012 14th Symposium on**. [S.l.], 2012. p. 147–154.

METATLA, O.; BRYAN-KINNS, N.; STOCKMAN, T. Constructing relational diagrams in audio: the multiple perspective hierarchical approach. In: ACM. **Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility**. [S.l.], 2008. p. 97–104.

METATLA, O. et al. Designing for collaborative cross-modal interaction. In: **Proc. of Digital Engagement 2011 the 2nd RCUK Digital Economy All Hands Meeting**. [S.l.: s.n.], 2011.

_____. Cross-modal collaborative interaction between visually-impaired and sighted users in the workplace. In: **Proceedings of The 18th International Conference on Auditory Display**. [S.l.]: Georgia Institute of Technology, 2012.

_____. Supporting cross-modal collaboration in the workplace. In: BRITISH COMPUTER SOCIETY. **Proceedings of the 26th annual BCS interaction specialist group conference on people and computers**. [S.l.], 2012. p. 109–118.

METAUML. 2018. Disponível em: <<https://github.com/ogheorghies/MetaUML>>. Acesso em: 15 Nov. 2018.

MICAS, L.; GARCEZ, L.; CONCEICAO, L. H. d. P. Com nova margem de corte, ibge constata 6,7% de pessoas com deficiência no brasil [In Portuguese]. **Estadão**, 2018. (Accessed on 2018-11-16). Disponível em: <<https://educacao.estadao.com.br/blogs/educacao-e-etc/com-nova-margem-de-corte-ibge-constata-67-de-pessoas-com-deficiencia-no-brasil/>>.

MILLER, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. **Psychological review**, American Psychological Association, v. 63, n. 2, p. 81, 1956.

MOUSTAKAS, K. et al. Using modality replacement to facilitate communication between visually and hearing-impaired people. **IEEE MultiMedia**, IEEE, v. 18, n. 2, p. 26–37, 2011.

MRECH, L. M. O que é educação inclusiva [In Portuguese]. **Revista Integração**, n. 20, p. 37–40, 1998.

MUELLER, J. **Accessibility for everybody: understanding the Section 508 accessibility requirements**. [S.l.]: Apress, 2008.

MÜLLER, K. **How to make Unified Modeling Language diagrams accessible for blind students**. [S.l.]: Springer, 2012.

MYNATT, E. D.; WEBER, G. Nonvisual presentation of graphical user interfaces: contrasting two approaches. In: ACM. **Proceedings of the SIGCHI Conference on Human Factors in Computing Systems**. [S.l.], 1994. p. 166–172.

NEALE, D. C.; CARROLL, J. M.; ROSSON, M. B. Evaluating computer-supported cooperative work: models and frameworks. In: ACM. **Proceedings of the 2004 ACM conference on Computer supported cooperative work**. [S.l.], 2004. p. 112–121.

NEGRY, K. C. **Situação de deficiência: a realidade de instituições de ensino superior do Distrito Federal à luz do atendimento prestado aos jovens estudantes com deficiência visual (cegos)** [In Portuguese]. Dissertação (Master's thesis) — Universidade Católica de Brasília, Brasília, 2012.

NIELSEN, J.; MOLICH, R. Heuristic evaluation of user interfaces. In: ACM. **Proceedings of the SIGCHI Conference on Human Factors in Computing Systems**. [S.l.], 1990. p. 249–256.

NVDA. 2018. Disponível em: <<https://www.nvaccess.org/>>. Acesso em: 15 Nov. 2018.

ODOM, S. L.; DEKLYEN, M.; JENKINS, J. R. Integrating handicapped and nonhandicapped preschoolers: developmental impact on nonhandicapped children. **Exceptional Children**, SAGE Publications Sage CA: Los Angeles, CA, v. 51, n. 1, p. 41–48, 1984.

OLIVEIRA, F. et al. Enabling multimodal discourse for the blind. In: ACM. **Proceedings of the International Conference on Multimodal Interfaces and the Workshop on Machine Learning for Multimodal Interaction**. [S.l.], 2010. p. 18.

- OLIVEIRA, L. S. D.; GEROSA, M. A. Collaborative features in content sharing web 2.0 social networks: A domain engineering based on the 3c collaboration model. In: SPRINGER. **International Conference on Collaboration and Technology**. [S.l.], 2011. p. 142–157.
- OWEN, C. B.; COBURN, S.; CASTOR, M. J. Teaching modern object-oriented programming to the blind: An instructor and student experience. In: **ASEE Annual Conference**. [S.l.: s.n.], 2014.
- PANSANATO, L. T.; SILVA, C. E.; RODRIGUES, L. Uma experiência de inclusão de estudante cego na educação superior em computação [In Portuguese]. In: **XX Workshop sobre Educação em Computação**. [S.l.: s.n.], 2012.
- PASTELLS, A. A. La integración de alumnos deficientes en la escuela ordinaria [In Spanish]. **Revista de Educación Especial, Barcelona**, n. 12, p. 44–57, 1993.
- PEFFERS, K. et al. A design science research methodology for information systems research. **Journal of management information systems**, Taylor & Francis, v. 24, n. 3, p. 45–77, 2007.
- PETERSEN, K. et al. Systematic mapping studies in software engineering. In: **EASE**. [S.l.: s.n.], 2008. v. 8, p. 68–77.
- PETRIE, H.; MORLEY, S.; WEBER, G. Tactile-based direct manipulation in guis for blind users. In: ACM PRESS. **Procs CHI'95 Conference Companion on Human Factors in Computing Systems**. [S.l.], 1995.
- PETRIE, H. et al. Tedub: A system for presenting and exploring technical drawings for blind people. In: **Computers helping people with special needs**. [S.l.]: Springer, 2002. p. 537–539.
- PIROLI, P. Cognitive models of human-information interaction. **Handbook of applied cognition**, John Wiley & Sons Ltd New York, NY, p. 443–470, 2007.
- PLANTTEXTUML. 2018. Disponível em: <<https://www.planttext.com/>>. Acesso em: 15 Nov. 2018.
- PLANTUML. 2018. Disponível em: <<http://plantuml.com/>>. Acesso em: 15 Nov. 2018.
- PRASAD, G. V. S.; DINESH, T.; CHOPPELLA, V. Overcoming the new accessibility challenges using the sweet framework. In: ACM. **Proceedings of the 11th Web for All Conference**. [S.l.], 2014. p. 22.
- PREECE, J.; SHARP, H.; ROGERS, Y. **Interaction Design: Beyond Human-Computer Interaction**. [S.l.]: John Wiley & Sons, 2015.
- PRESSMAN, R. S. **Software engineering: a practitioner's approach**. [S.l.]: Palgrave Macmillan, 2014.
- PROCTOR, R. W.; VI, K.-P. L. Innovation and intellectual property rights. In: JACKO, J. A. (Ed.). **Human Computer Interaction Handbook**. [S.l.]: CRC Press, 2012. cap. 2, p. 21–40.
- PROVOS, N.; MAZIERES, D. Bcrypt algorithm. In: USENIX. [S.l.], 1999.

PURAO, S.; ROSSI, M.; BUSH, A. Towards an understanding of the use of problem and design spaces during object-oriented system development. **Information and Organization**, Elsevier, v. 12, n. 4, p. 249–281, 2002.

QASYMPHONY. **The Cost of Poor Software Quality**. 2016. (Accessed on 11/22/2018). Disponível em: <<https://www.qasymphony.com/blog/cost-poor-software-quality/>>.

QS. **QS University Rankings - Latin America**. 2018. Disponível em: <<http://www.topuniversities.com/university-rankings/latin-american-university-rankings/2016>>. Acesso em: 15 Nov. 2018.

RAMLOLL, R.; BREWSTER, S. An environment for studying the impact of spatialising sonified graphs on data comprehension. In: IEEE. **Information Visualisation, 2002. Proceedings. Sixth International Conference on**. [S.l.], 2002. p. 167–174.

_____. A generic approach for augmenting tactile diagrams with spatial non-speech sounds. In: ACM. **CHI'02 Extended Abstracts on Human Factors in Computing Systems**. [S.l.], 2002. p. 770–771.

RAMLOLL, R. et al. Constructing sonified haptic line graphs for the blind student: first steps. In: ACM. **Proceedings of the fourth international ACM conference on Assistive technologies**. [S.l.], 2000. p. 17–25.

RASSMUS-GRÖHN, K.; MAGNUSSON, C.; EFTRING, H. E. Iterative design of an audio-haptic drawing application. In: ACM. **CHI'07 Extended Abstracts on Human Factors in Computing Systems**. [S.l.], 2007. p. 2627–2632.

ROYCE, W. W. Managing the development of large software systems: concepts and techniques. In: IEEE COMPUTER SOCIETY PRESS. **Proceedings of the 9th international conference on Software Engineering**. [S.l.], 1987. p. 328–338.

RUMBAUGH, J. et al. **Object-oriented modeling and design**. [S.l.]: Prentice-hall Englewood Cliffs, 1991. v. 199.

RUMBAUGH, J.; JACOBSON, I.; BOOCH, G. **Unified Modeling Language Reference Manual, The**. [S.l.]: Pearson Higher Education, 2004.

SAGE, M. **Declarative support for prototyping interactive systems**. Tese (Doutorado) — University of Glasgow, 2001.

SALLNAS, E.-L.; MOLL, J.; SEVERINSON-EKLUNDH, K. Group work about geometrical concepts among blind and sighted pupils using haptic interfaces. In: IEEE. **EuroHaptics Conference, 2007 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. World Haptics 2007. Second Joint**. [S.l.], 2007. p. 330–335.

SAVIDIS, A. et al. A generic direct-manipulation 3d-auditory environment for hierarchical navigation in non-visual interaction. In: ACM. **Proceedings of the second annual ACM conference on Assistive technologies**. [S.l.], 1996. p. 117–123.

SCHMIDT, K. The CSCW journal turns 20. **Computer Supported Cooperative Work**, v. 21, n. 6, p. 475–484, 2012.

SCHMIDT, K.; BANNON, L. Taking CSCW seriously. **Computer Supported Cooperative Work (CSCW)**, Springer, v. 1, n. 1-2, p. 7–40, 1992.

SCHOEBERLEIN, J. G.; WANG, Y. K. Evaluating groupware accessibility. In: SPRINGER. **International Conference on Universal Access in Human-Computer Interaction**. [S.l.], 2009. p. 414–423.

SEEDUML. 2018. Disponível em: <<https://github.com/skuro/seeduml>>. Acesso em: 15 Nov. 2018.

SEKKEL, M. C. **A construção de um ambiente inclusivo na educação infantil: relato e reflexão sobre uma experiência [In Portuguese]**. Tese (PhD thesis) — Universidade de São Paulo, São Paulo, 2003.

SEQDIAG. 2018. Disponível em: <<http://blockdiag.com/en/seqdiag/index.html>>. Acesso em: 15 Nov. 2018.

SHARMA, S. Designing novel gesture-based services for under served indian communities. In: ACM. **Proceedings of the 7th International Conference on HCI, IndiaHCI 2015**. [S.l.], 2015. p. 161–164.

SHENG, L. hua; XU, J. cheng. A research on web-based cooperative learning of hearing impaired university learner. In: IEEE. **Computer Science & Education, 2009. ICCSE'09. 4th International Conference on**. [S.l.], 2009. p. 1576–1579.

SHUJA, A. K.; KREBS, J. **IBM Rational unified process reference and certification guide: solution designer (RUP)**. [S.l.]: Pearson Education, 2007.

SILVA, C. E.; PANSANATO, L. T.; FABRI, J. A. Ensinando diagramas uml para estudantes cegos. In: **Proceedings of the 36th latin american informatics conference, Asunción, Paraguay**. [S.l.: s.n.], 2010.

SILVEIRA, C.; HEIDRICH, R. O.; BASSANI, P. B. Avaliação das tecnologias de softwares existentes para a inclusão digital de deficientes visuais através da utilização de requisitos de qualidade [In Portuguese]. In: **Brazilian Symposium on Computers in Education (Simpósio Brasileiro de Informática na Educação-SBIE)**. [S.l.: s.n.], 2007. v. 1, n. 1, p. 9–12.

SIMON, H. A. **The sciences of the artificial**. [S.l.]: MIT press, 1996.

SMITH, D. W.; KELLEY, P. A survey of assistive technology and teacher preparation programs for individuals with visual impairments. **Journal of Visual Impairment & Blindness**, ERIC, v. 101, n. 7, p. 429–433, 2007.

STEINMACHER, I.; CHAVES, A. P.; GEROSA, M. A. Awareness support in global software development: a systematic review based on the 3c collaboration model. In: SPRINGER. **International Conference on Collaboration and Technology**. [S.l.], 2010. p. 185–201.

SURVEYGIZMO. 2018. Disponível em: <<https://www.surveygizmo.com/>>. Acesso em: 15 Nov. 2018.

SURVEYMONKEY. 2018. Disponível em: <<https://pt.surveymonkey.com/>>. Acesso em: 15 Nov. 2018.

_____. 2018. Disponível em: <https://help.surveymonkey.com/articles/en_US/kb/508-Compliance/>. Acesso em: 15 Nov. 2018.

SWIGGER, K. M.; THOMAS, T.; BRAZILE, R. A computer-supported cooperative problem solving environment for examining communication effectiveness. In: IEEE. **Proceedings of International Conference on Intelligent and Cooperative Information Systems**. [S.l.], 1993. p. 98–103.

TAMMARO, S. G. et al. Collaborative writing is hard to support: a field study of collaborative writing. **Computer Supported Cooperative Work (CSCW)**, Springer, v. 6, n. 1, p. 19–51, 1997.

TANG, Z. et al. Collaborative rehabilitation support system: A comprehensive solution for everyday rehab. In: IEEE. **Multimedia (ISM), 2015 IEEE International Symposium on**. [S.l.], 2015. p. 61–64.

UFRGS. **Lista Geral da SBC [In Portuguese]**. 2018. Accessed January 16, 2018. Disponível em: <<https://listas.ufrgs.br/mailman/listinfo/Sbc-l/>>.

UMPLE. 2018. Disponível em: <<https://cruise.eecs.uottawa.ca/umple/>>. Acesso em: 15 Nov. 2018.

University of Washington. **Access Computing**. 2018. Disponível em: <<https://www.washington.edu/accesscomputing>>. Acesso em: 15 Nov. 2018.

VATRAPU, R.; SUTHERS, D. Intra-and inter-cultural usability in computer-supported collaboration. **Journal of Usability Studies**, Usability Professionals' Association, v. 5, n. 4, p. 172–197, 2010.

VIERITZ, H.; SCHILBERG, D.; JESCHKE, S. Access to uml diagrams with the hutn. In: **Automation, communication and cybernetics in science and engineering 2013/2014**. [S.l.]: Springer, 2014. p. 751–755.

W3C. Web content accessibility guidelines WCAG 2.0. **W3C Recommendation**, v. 11, 2008.

WADE, J. et al. Process measures of dyadic collaborative interaction for social skills intervention in individuals with autism spectrum disorders. **ACM Transactions on Accessible Computing (TACCESS)**, ACM, v. 10, n. 4, p. 13, 2017.

WANG, M. Atendendo alunos com necessidades especiais: equidade e acesso [In Portuguese]. In: **Caminhos para as escolas inclusivas**. [S.l.: s.n.], 1997.

WEBSEQUENCEDIAGRAMS - Draw UML sequence diagrams online in seconds. 2018. Disponível em: <<https://www.websequencediagrams.com/>>. Acesso em: 15 Nov. 2018.

WEEKLEY, E. **An etymological dictionary of modern English**. [S.l.]: Courier Corporation, 2012. v. 2.

WENTZ, B.; HOCHHEISER, H.; LAZAR, J. A survey of blind users on the usability of email applications. **Universal access in the information society**, Springer, v. 12, n. 3, p. 327–336, 2013.

WENTZ, B.; LAZAR, J. Email accessibility and social networking. **Online communities and social computing**, Springer, p. 134–140, 2009.

_____. Usability evaluation of email applications by blind users. **Journal of Usability Studies**, Usability Professionals' Association, v. 6, n. 2, p. 75–89, 2011.

WHITBURN, B. 'a really good teaching strategy': Secondary students with vision impairment voice their experiences of inclusive teacher pedagogy. **British Journal of Visual Impairment**, Sage Publications Sage UK: London, England, v. 32, n. 2, p. 148–156, 2014.

WHO, W. World report on disability. **Geneva: WHO**, 2011.

WICHMANN, B. A.; HILL, I. D. Algorithm as 183: An efficient and portable pseudo-random number generator. **Journal of the Royal Statistical Society. Series C (Applied Statistics)**, JSTOR, v. 31, n. 2, p. 188–190, 1982.

WIEGERS, K.; BEATTY, J. **Software requirements**. [S.l.]: Pearson Education, 2013.

WIKIPEDIA. **Lista de unidades federativas do Brasil por PIB [In Portuguese]**. 2018. Disponível em: <https://pt.wikipedia.org/wiki/Lista_de_unidades_federativas_do_Brasil_por_PIB>. Acesso em: 15 Nov. 2018.

WINBERG, F.; BOWERS, J. Assembling the senses: towards the design of cooperative interfaces for visually impaired users. In: ACM. **Proceedings of the 2004 ACM conference on Computer supported cooperative work**. [S.l.], 2004. p. 332–341.

WINOGRAD, T. From computing machinery to interaction design. **Beyond calculation: The next fifty years of computing**, New York: Springer-Verlag, p. 149–162, 1997.

YU, W.; BREWSTER, S. Evaluation of multimodal graphs for blind people. **Universal Access in the Information Society**, Springer, v. 2, n. 2, p. 105–124, 2003.

YUML. 2018. Disponível em: <<https://yuml.me/>>. Acesso em: 15 Nov. 2018.

ZAMBONI, A. et al. Start uma ferramenta computacional de apoio à revisão sistemática [In Portuguese]. In: **Proc.: Congresso Brasileiro de Software (CBSOFT'10), Salvador, Brazil**. [S.l.: s.n.], 2010.

ZAMZURI, N.; WANADNAN, W. The role of cognitive styles in groupware acceptance. In: SPRINGER. **International Conference on Human-Computer Interaction**. [S.l.], 2007. p. 835–845.

APPENDIX A – COMPUTER-SUPPORTED COLLABORATIVE WORK INVOLVING INDIVIDUALS WITH IMPAIRMENTS

This appendix presents the results of a systematic mapping we conducted on CSCW involving individuals with impairments.

The method used was a systematic mapping (PETERSEN et al., 2008) based on guidelines proposed by Kitchenham (KITCHENHAM, 2004) and Brereton et al. (BRERETON et al., 2007). This method involves a systematic search and examination of previously published studies about a subject. In contrast to the usual process of literature review, a systematic review is based on a defined search strategy that aims to reduce bias and detect as much of the relevant literature as possible.

The steps undertaken in this method involved: the development of a review protocol, a search for relevant studies, data extraction and synthesis from selected studies.

A.1 Systematic Mapping Protocol

The review protocol specified the research questions, search strategy, inclusion and exclusion criteria, data extraction, and methods of synthesis. Each one of these is discussed further below.

A.1.1 Research questions

The research questions addressed by this mapping were:

- RQ1: What are the studies that address CSCW involving individuals with impairments?
- RQ2: What impairments do they address?
- RQ3: Do studies follow frameworks or methods to support the inclusion process?
- RQ4: Do studies propose frameworks or methods to support the inclusion process?
- RQ5: Do studies propose new systems?

A.1.2 Data Sources and Search Strategy

We conducted searches with query strings on scientific sources of relevance to computer science area (BRERETON et al., 2007). The following sources were searched:

- ACM Digital Library;
- IEEE Xplore;

After this first step, for each identified study, we applied the inclusion and exclusion criteria described in section A.1.3.

We used the following query string for IEEE:

```
((("CSCL" OR "CSCW" OR "COMPUTER-SUPPORTED" OR "GROUPWARE") AND ("Abstract":"IMPAIRMENT" OR "Abstract":"DISABILITY" OR "Abstract":"IMPAIRED" OR "Abstract":"DISABLED" OR "Abstract":"HANDICAP" OR "Abstract":"HANDICAPPED" OR "Abstract":"SPECIAL NEED")))
```

For ACM, the following query string was used:

```
("CSCL" OR "CSCW" OR "COMPUTER-SUPPORTED" OR "GROUPWARE") AND recordAbstract:("IMPAIRMENT" OR "DISABILITY" OR "IMPAIRED" OR "DISABLED" OR "HANDICAP" OR "HANDICAPPED" OR "SPECIAL NEED")
```

A.1.3 Inclusion and Exclusion Criteria

Studies that were eligible for inclusion in the review if they were related to the inclusion of individuals with impairments in CSCW. Only peer-reviewed studies were included and we did not define any year constraint. The returned studies were reviewed by first reading the title and the abstract. When it was not clear whether the study covered the research questions, the paper was completely read.

A.1.4 Citation Management, Retrieval, and Inclusion Decisions

The whole process were recorded using a tool created to support systematic reviews (ZAMBONI et al., 2010).

A.1.5 Data Extraction

During this stage, data was extracted from studies according to a predefined extraction form. This form enabled us to record full details of the article under review and to be specific about how each of them addressed our research questions.

A.2 Results

The search results returned 128 entries, 57 from the ACM Digital Library and 71 from the IEEE Xplore. While reading the title and abstract, we discarded 64 entries considered not related to the subject. We also discarded 6 entries that were just cover pages and table of content. Additionally, we discarded 1 paper because it was not accessible through the USP access. In the full reading step, we discarded 21 papers considered not related to the subject. After discarding the papers, we ended with 36 papers to analyze, 17 from the ACM Digital Library and 19 from the IEEE Xplore. Table 41 shows a summary of these steps.

A.2.1 Selected papers

Tables 42 and 43 presented the papers selected for review.

In the next sections, we present some summarized data about these papers.

Table 41: Summary of the systematic mapping.

Description	ACM	IEEE	Total
Found	57	71	128
Title/Abstract	25	39	64
Not Content	1	5	6
Not available to download	0	1	1
When reading - not full paper	5	1	6
When reading - not related	9	5	14
When reading - not scientific paper	0	1	1
Selected	17	19	36

A.2.2 Volume of publication over the years

Figure 31 presents a chart with the number of papers per year. There is not a long term pattern in the number of publications, but it is possible to see a positive tendency since 2012.

Figure 31: Number of papers per year (Source: author).

A.2.3 Impairments and Disabilities

In relation to impairments, Figure 32 presents the number of papers per impairment/disability. The most common one is visual impairment, with 12 papers, followed by papers that covered not a specific impairment, with 7 papers.

A Research on Web-based Cooperative Learning of Hearing Impaired University learner (SHENG; XU, 2009)
A technical framework to support implicit structured collaboration (LINGNAU; BIENTZLE, 2009)
ACES: a cross-discipline platform and method for communication and language research (HAILPERN et al., 2013)
An Environment for Studying the Impact of Spatialising Sonified Graphs on Data Comprehension (RAMLOLL; BREWSTER, 2002a)
An Extended CSCW Architecture Using Wearable Personal Station-Based Korean Sign Language Recognizer (KIM; HONG, 2006)
An Initial Investigation into Non-Visual Computer Supported Collaboration (MCGOOKIN; BREWSTER; BREWSTER, 2007)
Assembling the senses: towards the design of cooperative interfaces for visually impaired users (WINBERG; BOWERS, 2004)
Augmentative and alternative communication: the role of broadband telecommunications (MCKINLAY et al., 1995)
Awareness elements on collaborative online editors from the perspective of people with visual impairment (MACHADO; CONFORTO; SANTAROSA, 2016)
Collaborative Rehabilitation Support System: A Comprehensive Solution for Everyday Rehab (TANG et al., 2015)
Collaborative Writing as a Mechanism of Interaction among Hearing Impaired and Listeners (BARRETO; DEUS; APOLONIO, 2010)
Constructing an MCSCL Groupware to Improve the Problem-solving Experience of Mathematics for Hearing-impaired Students (LIU et al., 2007)
Designing Novel Gesture-based Services for Under Served Indian Communities (SHARMA, 2015)
E-Learning with Computer Technology in Handicapped Higher Education (LI, 2009)
Enhancing pair learning of pupils with cognitive disabilities: Structural support with help of Floor Control (BIENTZLE et al., 2009)
From the war room to the living room: decision support for home-based therapy teams (KIENTZ et al., 2006)
Group Work About Geometrical Concepts Among Blind and Sighted Pupils Using Haptic Interfaces (SALLNAS; MOLL; SEVERINSON-EKLUNDH, 2007)
Harnessing iPad for lesson study within the triple-D framework in special education (CHIA; KEE, 2012)
"Helping Others Makes Me Happy": Social Interaction and Integration of People with Disabilities (LIU; DING; GU, 2016)

Table 42: A list of selected papers (first part).

Implementation of sound perception elements for visually impaired people in collaborative and synchronous Web systems (MACHADO; CONFORTO; SANTAROSA, 2017a)
Increasing workplace independence for people with cognitive disabilities by leveraging distributed cognition among caregivers and clients (CARMEN et al., 2003)
Intra- and Inter-Cultural Usability in Computer-Supported Collaboration (VATRAPU; SUTHERS, 2010)
Iterative design of an audio-haptic drawing application (RASMUS-GRÖHN; MAGNUSSON; EFTRING, 2007)
Mobile social networks as quality of life technology for people with severe mental illness (CHANG; LIU; WANG, 2009)
Overcoming The New Accessibility Challenges Using The Sweet Framework (PRASAD; DINESH; CHOPPELLA, 2014)
Perception for cooperation: Case study in web text editors from the perspective of blind users (MACHADO; CONFORTO; SANTAROSA, 2016)
Process Measures of Dyadic Collaborative Interaction for Social Skills Intervention in Individuals with Autism Spectrum Disorders (WADE et al., 2017)
Seamless worlds for people with physical disabilities "Teilhabe ohne Anwesenheit" (KARDUCK, 2000)
Socially Embedded Work: A Study of Wheelchair Users Performing Online Crowd Work in China (DING; SHIH; GU, 2017)
Soft computing agent approach to remote learning of disabled (LAKOV, 2004)
Sound chat: Implementation of sound awareness elements for visually impaired users in web-based cooperative systems (MACHADO; CONFORTO; SANTAROSA, 2017b)
Technology enhanced interaction framework and method for accessibility in Thai museums (ANGKANANON; WALD; GILBERT, 2015)
Telecommunication system for handicapped people (FERNANDEZ; ROA; CHÁVEZ, 2000)
Using Modality Replacement to Facilitate Communication between Visually and Hearing Impaired People (MOUSTAKAS et al., 2011)
Wiki for Visual Impaired People: Exploring New Possibilities of Collaboration (JATOBÁ et al., 2009)
xPress: Rethinking Design for Aging and Accessibility through a Voice-based Online Blogging Community (BREWER; PIPER, 2017)

Table 43: A list of selected papers (second part).

Figure 32: Number of papers per year (Source: author).

A.2.4 Groupware applications

Eighteen papers described the development of groupware to support collaborative activity. None of them followed a method nor a framework to do that. In sequence, we mention some of the groupware applications we have found.

Some of the developed groupware, focused on daily activities. Chang et al. (2009) developed a palmtop system that allows people with mental disabilities to go from home to work and vice-versa, as well as communicate their location to caregivers. Carmien et al. (2003) developed a distributed supportive system for people with cognitive disabilities.

Others have focused on communication issues. For instance, Jatoba et al. (2009) developed a Wiki for individuals with visual impairment, named DVWiki. Kin and Hong (2006) proposed a system for the recognition of the Korean language of signals using fuzzy logic. Moutaskas et al. (2011) developed a game that supports real-time communication and interaction between individuals with visual and hearing impairment.

When considering learning activities, Lakov (2004) used the same technique to develop a system for the inclusion of people with dyslexia in distance learning. Ramloll

and Brewster (2002a) analyzed the use of audio in the understanding of numerical data by people with visual impairment. Sallnas et al. (2007) studied the use of tactile feedback to identify geometric forms in group work involving a person with visual impairment and a sighted person.

A.2.5 Framework Proposal

Angkananon et al. (ANGKANANON; WALD; GILBERT, 2015) published the only paper that proposed a framework for groupware development. However, it focuses only in communication aspects and do not identify elements that may influence collaboration nor propose questions that may be made to orient the process. Jatoba et al. (JATOBÁ et al., 2009) proposed some questions to compare two groupware systems. Although they call these questions a framework, they are not generalizable.

In general, groupware is developed based only on traditional software engineering methods. Groupware support is tested only when experiments or user tests are conducted.

APPENDIX B – UML ACCESSIBILITY FOR INDIVIDUALS WITH VISUAL IMPAIRMENT

This appendix presents the results of a literature review we conducted on the accessibility of UML diagrams for individuals with visual impairment.

Unlike the literature on the accessibility of graphs, there are few studies related to the accessibility of UML models for individuals with visual impairment. We present the found studies classified according to the following criteria:

- diagrams studied;
- support for editing;
- form of information representation;
- interface type;
- interaction type;
- support for collaboration;
- integration with existing tools.

Some of these criteria are correlated. As an example, the multimodality of interface, interaction and the form of organization of information together define whether there is technological support for collaboration. This does not mean, however, that the occurrence of these factors guarantees the collaborative work, but only that in its absence collaborative work would not be possible.

With the exception of the first criterion, we address in the subsections referring to the other criteria only the studies that proposed computational solutions. This is justified because these criteria generally concern the characteristics of computational solutions.

B.1 Diagrams studied

King et al. (2004) and Petrie et al. (2002) proposed *Technical Diagram Understanding for the Blind* (TeDUB), a project designed to allow people with visual impairment to access information from various types of graphical models, four of them of UML: use cases, classes, sequence, and state.

The project, funded by the European Union, was initially aimed at obtaining information about diagrams through image recognition (PETRIE et al., 2002). However, developers encountered technical difficulties to implement this functionality (KING; EVANS, 2007). As an alternative, they used exchange files exported by CASE tools. In the case of UML diagrams, *XML Metadata Interchange* (XMI), a standard *Object Management Group* (OMG) format, was used to exchange information based on *eXtensible Markup Language* (XML). Files in the XMI format are generated by several UML CASE tools, such as Rational Modeler and PoseidonUML. A free version of TeDUB has been made available for download under the name AccessibleUML (KING, 2018). It allows users to import XMI 1.2 files (KING, 2011).

Grillo and Mattos Fortes (2014a) and Grillo et al. (2012) proposed AWMo, which allows both sighted users and users with visual impairment to access and edit UML class diagrams. The tool has been developed for the web and is free. Users with visual impairment can access and edit diagrams by means of a DSL defined by the authors. Sighted users can access and edit diagrams graphically, using the standard UML notation.

Coburn and Owen (2014) studied the use of physical objects (pins, cards and elastics) in the representation of information present in UML class and state diagrams. Since this approach requires translations between the representation based on physical objects and the one that sighted individuals are accustomed to use, the authors proposed a computational solution, known as Audible Browser, that supports the two

types of diagrams studied. Another solution based on physical objects was proposed by Brookshire(2006). The author used cards, plastic strips and pins to represent class diagrams. No name was given to the proposed solution.

Müller (2012) reported some difficulties to make UML models accessible to two students with blindness. The author also present strategies used to overcome the faced challenges. None of them involved the development of computational solutions. The first strategy involved the use of a tactile version of the diagrams, accompanied by textual descriptions. This version was generated with the Emprint tool (ViewPlus). The second one used tables to represent the diagrams. The diagrams covered were: classes, objects, and state.

Silva et al. (2010) proposed the use of Excel spreadsheets to represent and allow access and editing of use-case, class, and sequence diagrams by people with visual impairment. This solution is part of a project known as D4ALL. As part of this project, a computational solution has also been developed that allows access and editing of UML diagrams imported from other tools (PANSANATO; SILVA; RODRIGUES, 2012). It is not clear in the article which diagrams are implemented and the tool was not found for download.

Vieritz et al. (2014) used *Human-Usable Textual Notation* (HUTN) to represent activity and class diagrams. HUTN is a OMG pattern for storing model information in human-readable format. In a way, this notation can be seen as an alternative to XMI. The models were generated with *Eclipse Process Framework* (EPF) tools and translated to HUTN through Eclipse Epsilon. The solution proposed by Vieritz et al. (2014) did not involve the development of tools and access can be done by any text editor linked to a screen reader.

Loitsch and Weber (2012) developed HyperReader, which uses a touch-sensitive touchscreen developed by the authors. The display shows information through a region with 120x60 pins and allows direct manipulation by touch. The solution presented allows access to sequence diagrams.

Metatla et al. (2012a) have proposed a tool, known as *Collaborative Cross-modal Interfaces* (CCMI), whose purpose is to make collaborative work between sighted and people with visual impairment possible for some diagrams, such as the UML class di-

Table 44: Diagrams implemented by each proposed solution.

Study	Name	Implemented Diagrams													
		Activity	Class	Communic.	Components	Comp. Struc.	Deployment	Int. Overview	Object	Package	Profile	Sequence	State	Timing	Use Case
King et al. (KING et al., 2004; PETRIE et al., 2002)	TeDUB		✓									✓	✓		✓
Grillo e Fortes (GRILLO; FORTES, 2014a; GRILLO; FORTES; LUCRÉDIO, 2012)	AWMo		✓												
Coburn e Owen (COBURN; OWEN, 2014)	Audible Browser		✓										✓		
Brookshire (BROOKSHIRE, 2006)			✓												
Müller (MÜLLER, 2012)			✓						✓				✓		
Silva, Pansanato e Fabri (SILVA; PANSANATO; FABRI, 2010)			✓									✓			✓
Pansanato, Silva e Rodrigues (PANSANATO; SILVA; RODRIGUES, 2012)	D4ALL		Information not available												
Vieritz, Schilberg e Jeschke (VIERITZ; SCHILBERG; JESCHKE, 2014)		✓	✓												
Loitsch e Weber (LOITSCH; WEBER, 2012)	HyperReader												✓		
Metatla et al. (METATLA et al., 2012a)	CCml		✓												

agram. The only collaborative mechanism foreseen was blocking diagram elements. No sound or tactile feedback has been implemented to inform participants with visual impairment about changes made by other participants. According to the authors (METATLA et al., 2011), participants encountered difficulties in tracking the step-by-step progress of what their collaborators did during collaborative activities.

Table 44 presents the relationship between each of the solutions found in the literature and the respective implemented diagrams.

B.2 Support for editing

While some of the solutions allow access and editing of models, others allow only access to models created in other tools.

TeDUB, Audible Browser and HyperReader do not support model editing. As expected, this is an important feature for users. In tests performed with 34 users with visual impairment, King et al. (2004) reported that this functionality was highly demanded by participants. Other reviewed solutions (PANSANATO; SILVA; RODRIGUES, 2012; GRILLO; FORTES, 2014a; GRILLO; FORTES; LUCRÉDIO, 2012; METATLA et al., 2012a) allow model editing.

B.3 Form of representation of information

As for the representation of the information present in models, the studies can be categorized into five categories, divided into two groups:

- Without transformation:
 - Maintained the original form of the model;
- With transformation:
 - They transformed the model into a textual representation using some DSL;
 - They transformed the model into a tabular representation;
 - They transformed the model into a hierarchical representation;

Some solutions have maintained the original graphical representation of the model (without transformations) as one of the possible representations. This is the case of TeDUB, D4ALL, HyperReader, AWMo and CCml. The original representation of the model in TeDUB, D4ALL, Audible Browser and CCml can be used by both sighted people and people with visual impairment. In TeDUB, the user can use navigation keys or a joystick to navigate through the diagram elements. In this type of navigation, 3D audio is used to reinforce the position of the joystick. In D4ALL, visually impaired users should use the keyboard to navigate from the upper left corner to the lower right corner. In the Audible Browser, visually impaired people can obtain information about positioning the elements of models via audio.

In studies involving transformations, TeDUB performs a transformation to a hierarchical representation (a tree). In this representation, the data is presented in six separate fields, which specify: the currently selected node, information about that node, its connections, information about these connections, annotations and joystick (indicates which node is located in the direction currently indicated by the joystick) . The Audible Browser also performs a transformation for hierarchical representation for keyboard navigation. Four fields are used, which display the following information: classes, attributes, operations, and associations. The CCml, in turn, transforms a model into a hierarchical representation that can be navigated and edited through the keyboard.

Some papers involved the transformation of diagrams into textual representations. This is the case of the solution proposed by Vieritz et al. (2014), which involved the transformation of models to HUTN. Just for comparison (in an experiment) with the solution developed by the authors, Loitsch and Weber (2012) converted some diagrams into tactile textual (linear) representations. Grillo and Mattos Fortes (2014a) and Grillo

et al. (2012) used a DSL to represent class diagrams. AWMo is the only solution that involves the use of DSL to represent models.

B.4 Interface Types

The interfaces of the solutions can be classified into the following categories:

- graphical item with text (for access through screen readers);
- graphical item with diagrams;
- sound item (reproduction of musical tones or specific sound signals);
- tactile item (objects, printed or on specific hardware).

Solutions based on graphical interfaces with text are: TeDUB, Audible Browser, D4ALL, AWMo, and CCml. Of these, some are multimodal regarding the interface, providing other types of information presentation (KING et al., 2004; PETRIE et al., 2002; COBURN; OWEN, 2014; PANSANATO; SILVA; RODRIGUES, 2012; METATLA et al., 2012a).

In order to offer a unique environment where both sighted people and people with visual impairment can act, some solutions implement a graphical representation of the models in their original notation. TeDUB allows visualization of diagrams if a *Scalable Vector Graphics* (SVG) viewer is available. D4ALL also allows the display of diagrams in its graphical version. AWMo and CCml, besides allowing the visualization of the models in their graphic form, still allow them to be edited with the mouse.

The solutions that implement sound interfaces are: TeDUB, Audible Browser, and CCml. TeDUB uses audio signals to notify you of aspects of navigation, such as when you visit a node that does not contain children. The Audible Browser displays the x and y position of a model element by means of variations in sound volume and spatial location, respectively. CCml uses feedback signals during model navigation.

Of the solutions with tactile interfaces, King et al. (2004) report that a tactile version of TeDUB was in development. However, no published results or related functionality

has been found. HyperReader uses a touchtable to allow access to sequence diagrams. The CCml, in turn, in addition to the graphical interfaces, uses a haptic device to allow visually impaired and sighted to explore models.

B.5 Interaction Types

Among the types and devices of interaction implemented in the solutions found are:

- joystick;
- keyboard:
 - shortcuts;
 - menu;
 - navigation keys;
- tactile item;
- mouse;

Of the solutions reviewed, the only one that supports joystick use is TeDUB. In this solution, the joystick can be used to navigate an original representation of a diagram and to obtain information from the targeting of a specific part of it. The authors note that this is a simple system, but suffers from a failure when multiple nodes are connected and located in the same direction. In this case, the system displays only the name of the nearest node. In tests performed by the authors, the diagrams were prepared in order to avoid this.

Interfaces that produce graphical representations of diagrams according to UML notation can be navigated using the mouse, but in this case, the target users are (GRILLO; FORTES, 2014a; GRILLO; FORTES; LUCRÉDIO, 2012). Although less common, some solutions use the mouse for visually impaired individuals. This is the case of the Audible Browser, where the mouse can be used for users to navigate through the diagram (the audio reproduced for the diagram is related to the mouse positioning).

The D4ALL also allows navigation through the original representation of diagrams, but via the keyboard. It allows you to traverse the entire diagram from the element closest to the upper left corner, following Cartesian coordinates to the element closest to the lower right corner. Other solutions that involve using the keyboard are: TeDUB, Audible Browser, HyperReader and, AWMo, but in this case, not for navigation through the original representation of diagrams.

HyperReader also allows the user to interact with touch diagrams on the touchpad developed by the authors (LOITSCH; WEBER, 2012), as well as buttons that can be attached to the table (for diagram navigation). Finally, CCml allows the use of a haptic device to navigate through the original representation of diagrams.

B.6 Support for collaboration

As far as collaboration is concerned, TeDUB and the Audible Browser do not implement support mechanisms.

HyperReader enables one-way collaboration: When a sighted user changes the diagram in Microsoft Visio, the user with visual impairment can use the touchpad to navigate the diagram. Users with visual impairment can not edit the diagram. AWMo allows collaboration, but not real-time. Each participant should wait for the other to make their changes to then view the model. This is also the behavior observed in D4ALL. In these cases, no feedback is provided to participants on the changes being made. The CCml, in turn, allows for real-time collaboration, but does not implement any mechanism that informs participants about the current state of the model and the modifications being made.

B.7 Integration with existing tools

Of the proposed solutions, some can be integrated with existing tools through the import / export of intermediate formats, such as XMI. TeDUB integrates with tools that export file XMI version 1.2. Audible Browser, in turn, integrates with tools that export XMI version 2.1 files, such as Visual Paradigm. HyperReader integrates with Microsoft Visio 2007, providing an alternate representation for the diagram viewed in the tool.

D4ALL also supports import / export of XMI files.

The other revised solutions do not implement mechanisms for integration with existing tools (GRILLO; FORTES, 2014a; GRILLO; FORTES; LUCRÉDIO, 2012; METATLA et al., 2012a).

An interesting feature of solutions that allow integration with existing CASE tools is that sighted people do not need to create special-format diagrams for individuals with visual impairment.

APPENDIX C – ON THE INCLUSION OF INDIVIDUALS WITH VISUAL IMPAIRMENT IN COMPUTING EDUCATION PROGRAMS

This appendix presents the results of a survey we conducted to study the inclusion of individuals with visual impairment in computing education programs. These results were published in the Journal of the Brazilian Computer Society (LUQUE et al., 2018).

C.1 Background

There are various legal instruments that assure people with impairments the right to an inclusive scenario (Brazil, 2018c; Brazil, 2018a; Brazil, 2018b). Among these, the administrative ordinance (*Portaria*) no. 1,679 (Brazil, 2018c) defines the requirements for accessibility in higher education and the Statute of People with Disabilities (*Lei Brasileira de Inclusão da Pessoa com Deficiência*) (Brazil, 2018a) highlights the right to an inclusive education at all levels, as quoted next.

"Education is a right of individuals with impairments that must be secured at all educational levels [...], in order to achieve the maximum possible development of their talents and their physical, sensory, intellectual, and social skills, according to their characteristics, interests and learning needs [...]. It is a public authority incumbency to ensure, create, develop, implement, encourage, monitor and evaluate: [...] XIII - Access to higher and technological education in equal opportunities and conditions [...]" (translated by the authors)

Unfortunately, the scenario as provided by law does not correspond to reality. Courses in many educational levels and fields of knowledge are still inaccessible to visually impaired learners (ALBINO, 2010; CHAHINI, 2005; CRUZ, 2012; GUERREIRO; ALMEIDA; FILHO, 2013; NEGRY, 2012) due to institutions' internal and external factors.

When considering higher education, the main external factors that influence learner enrollment are related to selection exam accessibility, quality of lower education levels, and transportation accessibility. In Brazil, candidates to higher education must be approved in a selection exam (FRANCO, 2013). To give equal conditions in such exams to individuals with visual impairment, the selection exam must be accessible. In addition, the education at lower levels must have been effective so that the candidate has equal conditions to compete. Transportation accessibility is important not only prior to learner enrollment, but during the whole course period. Internal factors include the lack of accessibility in the physical environment, educational material, pedagogical methods, cultural aspects such as prejudice, among others.

Amiralian and Masini (AMIRALIAN, 2002) and Mrech (MRECH, 1998) consider two pedagogical conceptions to the inclusion of learners with impairments in education programs. The first conception, called normalization, is aimed at making learners with impairments similar to other classmates. In this conception, the educator is not generally supported by an expert in special education. Learners with impairments have to show their ability to attend regular classes. The other conception seeks to understand how they are constituted and perceive the world in order to adapt material and pedagogical methods. This conception does not seek to normalize them or to impose concepts, standards and values of sighted people.

Several studies have shown that inclusive education is more beneficial than segregated education for all students (WANG, 1997; ODOM; DEKLYEN; JENKINS, 1984; PASTELLS, 1993; SEKKEL, 2003). These surveys, focused on K12 education, show that both learners with impairments and sighted learners gain from this coexistence, and there are no records of any adverse effects on learning or socialization processes. Adverse effects, however, are noticeable when learners with impairments are simply enrolled and attend regular programs, without an environment that welcomes and values differences.

C.2 Inclusion of visually impaired learners in the computing field

In computing education programs, the frequent required use of charts, graphs, and diagrams creates additional obstacles to visually impaired learners. Some examples of graphical notations and disciplines that use them are: (i) BPMN - Business Process Model and Notation, MSD - Module Structure Diagram, DFD - Data Flow Diagram, MHD - Module Hierarchy Diagram, IDEF - Integrated DEFinition Methods, SysML - Systems Modeling Language, and UML - Unified Modeling Language (Software Engineering); (ii) flowcharts (Software Engineering, Algorithms and Data Structures, and Programming Language); (iii) graphs and their subtypes, such as trees (Algorithms and Data Structures, Analysis of Algorithms, Graph Theory, Artificial Intelligence, Performance Analysis, Compilers, Formal Languages, Software Testing, and Automata and Computability); (iv) Petri nets (Distributed Systems); (v) ERD - Entity-Relationship Diagram (Database and Software Engineering)

Educators use such graphical representations to teach and to exemplify concepts (OWEN; COBURN; CASTOR, 2014), and visually impaired learners are sometimes not allowed to express their knowledge through alternative tasks (MÜLLER, 2012). In order to convey information in graphical representations to visually impaired learners in classroom activities, educators would have to receive support from assistants or use low/high-tech assistive technologies (DELL; NEWTON; PETROFF, 2016). Examples of low-tech assistive technologies are tools such as pens or tactile drawings (LOITSCH; WEBER, 2012), and physical objects with specific semantics (BROOKSHIRE, 2006; MCMULLEN; FITZPATRICK, 2009). Examples of high-tech assistive technologies are tactile displays (GILKES; COWENS; TAYLOR, 1996), Optical Character Recognition (OCR) (CHARLES et al., 2012), screen readers (BORODIN et al., 2010), among others.

In addition to the accessibility of graphical content, the accessibility of software systems used in computing education programs, such as IDE - Integrated Development Environment and CASE - Computer-Aided Software Engineering, is also important to make inclusion possible.

Over the last 20 years, many studies on the inclusion of visually impaired learners in the computing field have been published. Some of them reported experiences re-

lated to teaching computing topics, such as object-orientation, graphs, and the UML, to visually impaired learners (OWEN; COBURN; CASTOR, 2014; BROOKSHIRE, 2006; COHEN; MEACHAM; SKAFF, 2006; CONNELLY, 2010; PANSANATO; SILVA; RODRIGUES, 2012; SILVA; PANSANATO; FABRI, 2010). Other studies focused on haptic and multimodal interaction with computing diagrams for individuals with visual impairment (BLENKHORN; EVANS, 1998; IGLESIAS et al., 2004; LÖTZSCH, 1994; OLIVEIRA et al., 2010; RAMLOLL et al., 2000; YU; BREWSTER, 2003). Yet, other studies covered textual and audio-based interfaces to convey the content of computing diagrams to individuals with visual impairment (KING, 2018; KING, 2011; COHEN et al., 2005; KENNEL, 1996; KING et al., 2004; METATLA; BRYAN-KINNS; STOCKMAN, 2008; PETRIE et al., 2002; VIERITZ; SCHILBERG; JESCHKE, 2014). These studies considered both linear and hierarchical access to diagram content. Finally, other studies covered collaborative diagram-based activities involving individuals with visual impairment (GRILLO; FORTES, 2014a; GRILLO; FORTES; LUCRÉDIO, 2012; LUQUE et al., 2014; LUQUE et al., 2015a; LUQUE; BRANDÃO; BRANDÃO, 2016).

Despite the extensive research on the subject, further research and technological development effort are required to produce a more inclusive scenario (LUQUE et al., 2015a; CAPOVILLA; MÜHLING; HUBWIESER, 2015). An important step toward such inclusive scenario is to gather information from the parties involved. This information is required to establish appropriate action plans by institutions, educators, and decision makers.

Considering this context and the absence of such information for computing education in Brazil, this appendix presents the results of a survey with visually impaired learners and educators in computing education programs. This survey was conducted to gather information about the practice and perceptions of learners regarding their inclusion and of educators when visually impaired learners attend their lectures.

In the discussion subsection, we talk about some alternatives to promote a more inclusive scenario. In addition, we believe the information present in this paper may guide and support the definition of procedures and policies to promote a more inclusive scenario.

C.3 Methods

We conducted a survey using questionnaires aimed at identifying the practice and perceptions of educators and visually impaired learners regarding their inclusion in computing education programs. Particularly, we aimed at gathering information about the following aspects:

- Institutional provision for educators and learners;
- Changes in didactic methods (lecture style, accessibility of graphical representations, assessment, and group activities);
- Perception of changes in didactic methods.

The research was carried out by sending electronic questionnaires, with multiple choice and short answer questions, targeting two distinct groups: (i) educators in the field who have taught visually impaired learners; and (ii) visually impaired learners who have attended courses in the field. The questionnaires for educators and learners may be found at <https://github.com/leluque/jbcs>.

Educators were contacted through the *Sociedade Brasileira de Computação (In Portuguese)* (SBC) general list (UFRGS, 2018). An invitation e-mail was sent to everyone in the list. The list has about 7650 members, which comprises professionals, educators, and students in the computing field. There is no available data regarding the number of educators in the list. Visually impaired learners, on the other hand, were contacted through the Blind Programmers list (FORUM, 2018), which has individuals with visual impairment working in the computing field. An invitation e-mail was sent to everyone in the list. The list has about 180 individuals with visual impairment that are in the computing field.

The questionnaire for educators was created using Google Docs forms (DOCS, 2015), and SurveyMonkey (SURVEYMONKEY, 2018a) was used for learners considering the lack of accessibility of the former to individuals with visual impairment (BUZZI et al., 2010). SurveyMonkey advertises its compliance with Section 508 (MUELLER, 2008) and WCAG 2 (CONSORTIUM et al., 2008; SURVEYMONKEY, 2018b). In addition, other studies in the literature use SurveyMonkey to apply questionnaires to individ-

uals with visual impairment (WENTZ; LAZAR, 2009; WENTZ; LAZAR, 2011). Finally, we had already assessed the SurveyMonkey accessibility in previous surveys.

The questionnaires were released to receive responses from June 12 to October 16, 2015. The responses were analyzed through descriptive statistics - generation of contingency tables and calculation of percentages.

C.4 Results: educators' practices and visually impaired learners' perceptions

In this section, we present the results of the survey. First, we present the results for the questionnaire filled in by educators. Then, in the second subsection, we present the results for the questionnaire filled in by learners.

C.4.1 Results for educators

The questionnaire received 56 responses. All respondents have had experience of teaching computer science subjects to visually impaired learners.

C.4.1.1 Institutional provision

Regarding institutional provision, we asked educators if they had received any kind of information or training from the institution to teach visually impaired learners.

From the 56 respondents, only 12, which corresponds to 21%, declared to have received institutional provision in terms of training or information. The majority of educators, 44, which corresponds to 79%, declared not having received such provision.

Among the educators' comments regarding institutional provision, we can quote:

"Teaching students with visual impairment was a challenge for me. I have not received instructions (...) and I had to (handle the situation all by myself)."

"It was an interesting experience dealing with this situation. I could see how unprepared we are to receive students with any kind of difficulty. Anyway,

my adaptation to the new situation was quick and I believe for other educators as well, but it is necessary to rethink the teaching strategies to improve inclusion."

"[...] I understand that many educators feel unprepared to carry out the task of teaching students with visual impairment. Teaching professionals need to receive training and to develop the skills required to teach students with special needs."

Learners assessment and group work

Regarding learner assessment and group work, we asked educators if they have involved visually impaired learners in group activities and assessed them differently.

Out of 56 educators, the majority, 47, which corresponds to 84%, declared to have involved visually impaired learners in group activities with other learners. The other 9 educators declared not to have involved such learners in group activities.

Regarding learner assessment, out of 56 educators, 27, which corresponds to 48%, declared to have assessed visually impaired learners differently from sighted learners. The other 29 educators declared not to have assessed them differently.

C.4.1.2 Lecture style and educational material

From the 56 educators, 47, which corresponds to 84%, have used the blackboard in their lectures. Since visually impaired learners cannot access the blackboard content, we asked educators if they have changed the lecture style when teaching visually impaired learners. From these 47 educators, 6 did not change anything in their lectures when teaching visually impaired learners. Among the 41 educators who have changed the lecture style, we identified 5 strategies they used. These strategies are listed next.

- Using a specific part of the blackboard (for learners with low vision);
- Changing font size (use of larger fonts);
- Delivering accessible material after the lecture;

- Delivering accessible material prior to the lecture;
- Changing verbalization - Repetitively verbalized the blackboard content;

Figure 33 presents the frequency of use of each strategy (individually and combined).

The most common strategy used by educators was delivering material prior to the lecture. This was the only strategy used by 30 educators. Changes in verbalization was the only strategy used by 6 educators. Two (2) other educators combined delivering material prior to the lecture with changes in verbalization. Other strategies were mentioned only once.

Figure 33: Frequency of use of each strategy individually and in combination by 41 educators who kept using blackboards in their lectures (Source: author).

C.4.1.3 Approaches to make graphical representations accessible

From the 56 educators, 40, which corresponds to 71%, taught subjects that involved the use of graphical representations. For those who use graphical representations, we inquired about the approaches used to make graphical representations accessible to visually impaired learners. From these 40 educators, 3 answered they did not know any approach to make graphical representations accessible to visually impaired learners. Among the remaining 37 educators that knew some approach, 2 did not use any. The remaining 35 educators mentioned 6 different approaches they used. These approaches can be classified according to the sensory perception they are based on (hearing, touch, and sight), as described next.

The approaches based on hearing comprise: (i) textual description, in which a textual description of the graphical content was provided to learners prior to the lecture - the textual description was synthesized by screen readers; (ii) verbal description, in which the graphical representation content was read aloud by the educator during the lecture; (iii) assistant support, in which the graphical representation content was read aloud by an assistant during the lecture.

Regarding touch, the following approaches were used: (iv) physical objects, in which physical objects were used to represent the graphical representation content; (v) tactile representations in paper, in which raised representations, both printed and created with special pens, were used to represent the graphical representation content. Some educators also used Braille to represent textual elements of the graphical representation.

For learners with low vision, amplification (sight) was used to make the access feasible to the graphical representation in its original representation.

The most used sense, individually and in combination, was hearing (Figure 34). Verbal description, assistant support, or textual description (read by screen readers) was mentioned by 35 respondents that used some approach. Among these, textual description was the most widely used approach, mentioned by 30 educators (85% of the educators that used some approach). In most cases, 17, textual description was used alone. Touch-based approaches were used individually by 3 educators (9%) and in combination with hearing by 12 educators (34%). Among these, tactile representations were mentioned by 10 out of 35 (29%) respondents. Sight-based approaches were mentioned by only 2 educators.

C.4.1.4 Influence of institutional provision in other aspects

In order to investigate if institutional provision may influence inclusion in group activities, appropriate assessment, change in lecture style over the blackboard, and accessibility of graphical representation, we constructed contingency tables (Tables 45 to 48).

As shown in Table 45, from those educators who had institutional provision, 10 out of 12 (83%) involved visually impaired learners in group activities. For those who not

Figure 34: Frequency of use of each approach used by 35 educators to make graphical representations more accessible (Source: author).

		Involved in group activities		
		No	Yes	
Institutional Provision	No	7	37	44
	Yes	2	10	12
		9	47	56

Table 45: Contingency table of institutional provision by including learners in group activities.

had institutional provision, 37 out of 44 (84%) involved such learners in group activities. Such small difference indicates that it is not possible to perceive a statistical relation between institutional provision and the inclusion of visually impaired learners in group activities.

With respect to assessing visually impaired learners (Table 46), about 50% of the educators, with or without institutional support, declared to use different assessment strategies.

Therefore, by Tables 45 and 46, the institutional provision does not have influence over the educator with respect to including visually impaired learners in group activities and to assess them differently.

		Assessed learners differently		
		No	Yes	
Institutional Provision	No	22	22	44
	Yes	7	5	12
		29	27	56

Table 46: Contingency table of institutional provision by use of different assessment strategies for visually impaired learners.

		Made graphical representations accessible		
		No	Yes	
Institutional Provision	No	5	24	29
	Yes	0	11	11
		5	35	40

Table 47: Contingency table of institutional provision by using some strategy to make graphical representations accessible.

		Changed lecture style over blackboard		
		No	Yes	
Institutional Provision	No	6	33	39
	Yes	0	8	8
		6	41	47

Table 48: Contingency table of institutional provision by changes in lecture style for educators that have used the blackboard.

However, institutional provision seems to influence the classroom dynamics in terms of changing lecture style over blackboard and making graphical representations accessible. In fact, all educators with institutional provision declared to have made these changes, as shown in Tables 47 and 48. In contrast, from those educators who had not had institutional provision, 84% declared to have made these changes.

C.4.2 Results for learners

In this subsection, we present the results for the questionnaire filled in by learners.

There were 31 respondents to the visually impaired learners questionnaire, of whom 19 were considered valid. We considered invalid those responses that were incomplete and contained only information about the learner's degree of visual impairment.

The respondents include 7 learners that are currently attending a computing education program, corresponding to 37% of all respondents, and 12 learners that previously attended a program in the field, corresponding to 63%. From those that have already attended a program in the field, only one did not complete the program.

Regarding their degree of visual impairment, 16 learners (84%) declared to be completely blind and 3 (16%) as having low vision.

About 50% of the learners have more than 12 years of experience using computers and 1 year as professionals in the field. All of them have at least 5 years of experience as users. The most experienced user has been using computers for 16 years.

C.4.2.1 Educational level and institutions

When considering the educational level they attended, 14, corresponding to 74%, attended higher education programs. The other 5, corresponding to 26%, attended certification (known as 'technical' in Portuguese) or professionalizing programs.

Higher education institutions in 5 different states were attended by learners: (i) MT - Mato Grosso: UNIVAG - Várzea Grande University Center; (ii) PR - Paraná: UNICESUMAR - Maringa University Center and UTFPR - Federal University of Technology of Parana; (iii) RS - Rio Grande do Sul: UCS - University of Caixas do Sul; (iv) RJ - Rio de Janeiro: Estácio de Sá University; (v) SP - Sao Paulo: Anhanguera Faculty, Impacta Faculty, SENAC, UNICAMP - University of Campinas, UNICID - University of the City of Sao Paulo, UNIP - Paulista University, and USP - University of Sao Paulo. This group includes two of the best Brazilian universities considering international rankings (QS, 2018)

C.4.2.2 Difficulties due to visual impairment

The learners were asked if they faced any difficulty due to their impairment in the courses. Only one of them answered he/she did not face any difficulty due to the impairment. This learner is completely blind and attended a short professionalizing course in a non-regular educational institution. All learners in universities and certification institutions reported difficulties.

One learner highlighted the lack of institutional provision in terms of infrastructure and assistance.

"(I felt a) lack of proper (institutional) support ... They provided the minimum ... I ... filled in the questionnaire about disabilities ..., asking (for) a(n) (assistant) to help me in the classroom, so that I could (have a better interaction) ..., but I did not receive any support. (The results of the education process)

depended mainly on the good will of the (educators). There were no tactile floors and means to locate myself ..."

In addition to the lack of institutional provision, another learner highlighted a lack of educator's knowledge about the peculiarities of visual impairment.

"(I noticed a) ... lack of (educators) knowledge about the peculiarities of visual impairment. For example, the educators have an ingrained habit of pointing the items in the slides without mentioning their names or giving more details about the layout of the content. (Additionally, there were) laboratories with computers without screen readers and EAD platforms (that did not meet) the minimum accessibility requirements."

C.4.2.3 Accessible books and assistant support

The learners were asked about the availability of accessible books and of assistant support during the program. They had to answer using a Likert scale, from Strongly Disagree (1) to Strongly Agree (5), the following statements: 'All books in my course syllabus were accessible' and 'I have had assistant support in all lectures in my course'.

Figure 35: Frequency and percentage of response to the statement 'All the books in my course syllabus were accessible' (Source: author).

Figures 35 and 36 present their responses. Out of 19 learners, 2 did not answer these questions. Among the 17 respondents, 4 learners, corresponding to 24%, reported to have had access to accessible versions of all the books used in the program or to assistant support in all lectures. In fact, 3 of them answered 'Strongly Agree' to both questions. Two others chose this answer to only one of the questions. On the

other hand, 5 learners, corresponding to 29% of the respondents, reported to have had no access to accessible versions of all the books used in the program.

Regarding assistant support, 4 learners, which corresponds to 24%, reported not to have had access to assistant support in all lectures. Other 4 learners reported to have had access to assistant support in all lectures.

Figure 36: Frequency and percentage of responses to the statement 'I have had assistant support in all the lectures in my course' (Source: author).

C.4.2.4 Approaches educators used to make graphical representations accessible

We asked learners about the approaches their educators used to make graphical representations accessible. Among the 19 learners, 5 of them did not answer the question. Among the 14 who responded, 5, corresponding to 36%, answered that no approach was used, so that they did not have access to any graphical representation. The other 9 respondents mentioned 5 different strategies used by educators. As for educators, these strategies can be grouped by sensory perception. Hearing-based approaches comprise textual and verbal description. Touch-based approaches comprise multiplan, tactile drawings, and Braille impressions.

In Figure 37, we present the frequency of response. The most widely used sense was touch. It was used individually by 4 (29%) educators and in combination with hearing by 3 (21%) educators. Among the touch-based approaches, tactile drawings was the most often mentioned.

Figure 37: Frequency of approaches by sensory perception their educators used to make graphical representations accessible (Source: author).

C.4.2.5 Collaboration with classmates related to graphical representations

Regarding collaboration among visually impaired learners and classmates in lectures that involved the use of graphical representations, 4 learners did not answer the question. From the 15 respondents, 7, which correspond to 47%, reported they were not involved in group activities and did not interact with classmates; and 8 reported to use textual descriptions, tactile representations or counted on classmates support, as shown in Figure 38. The most widely used approach was textual and verbal description together, answered by 5 respondents, which correspond to 33% of all question respondents. Classmate help was used by 2 learners and tactile drawing by 1 learner.

C.4.2.6 Assessment

The learners were also asked about the way they were assessed in subjects that involved the use of graphical representations. As 4 learners did not answer this question, we present the results for 15 respondents in Figure 39.

Among the 15, 6 (40%) were assessed regarding their conceptual knowledge about the subject. Other 5 respondents, which correspond to 33% answered they were not assessed at all. Classmate/assistant help was answered by 2 respondents. Finally, oral assessment and tactile drawings were mentioned by 1 learner each.

Figure 38: Frequency of use of each strategy learners used to collaborate with educators and classmates in lectures that involved the use of graphical representations (Source: author).

Figure 39: Strategies used to assess learners in subjects that involved the use of graphical representations (Source: author).

C.4.2.7 Problematic topics

We asked visually impaired learners about the topics they consider the most challenging in the courses they have taken. The following topics were mentioned by learners: (i) Applied Math; (ii) Analytical Geometry; (iii) Linear Algebra; (iv) Discrete Math; (v) Computer Graphics; (vi) Physics; (vii) Formal Languages; (viii) Automata and Computability; (ix) Software Engineering; (x) Database; (xi) Web Technology; (xii) Calculus; (xiii) Mobile Programming; (xiv) Computer Networks; (xv) Digital Circuits; (xvi) Algorithms; and (xvii) Visual Programming Languages.

The number of subjects mentioned by learners comprises a significant part of computing education programs. In courses such as Computer Science and Computing Engineering, learners mentioned theoretical topics that form the foundation of the field (e.g. Discrete Math, Formal Languages, and Automata and Computability). In courses such as Information Systems and Systems Analysis and Development, central disciplines (Software Engineering, Database, Web Technology, Visual Programming Languages, and Mobile Programming) were mentioned by learners. This amplitude of challenges reinforces the necessity of further research and technological development effort.

C.5 Discussion

In the following subsections, we discuss the aforementioned results.

C.5.0.1 Results contextualization

The results we present are related to institutions in 5 different Brazilian states: (i) MT - Mato Grosso; (ii) PR - Paraná; (iii) RS - Rio Grande do Sul; (iv) RJ - Rio de Janeiro; and (v) SP - Sao Paulo. While one must analyze the results considering its spatial contextualization, the aforementioned 5 states contain about 48% of the main computing-related undergraduate courses in Brazil (Computer Science, Computer Engineering, Information Systems, and System Analysis and Development) (MEC, 2017). Furthermore, 9 of the 15 best Brazilian educational institutions according to the Times Higher Education (EDUCATION, 2018) are located in these states and we gathered

data about 2 of them. In addition, they include 4 of the 5 most rich Brazilian states, considering their gross domestic products (WIKIPEDIA, 2018). Considering that, it is expected that the inclusion scenario in these institutions represent part of the best scenario in educational institutions in Brazil.

C.5.0.2 Class style and material

It is well known that blackboard content is not accessible to visually impaired learners. Most educators used blackboards in their lectures. The most widely used strategy by educators to deliver material to learners is 'delivery of material prior to lecture', and despite being usefull to allow visually impaired learners to follow explanations, this may result in inflexibility in the class content, which can harm the teaching and learning process.

This inflexibility may prevent free interactions between learners and educators, negatively influencing the educational processes. Also, it may increase the sense of distance between participants (LUQUE et al., 2015a). For instance, content and examples based on situations raised in class, which could increase the learner's motivation, can hardly be applied in such an inclusive scenario.

Approaches that could be adopted to keep the blackboard lecture style, without creating inflexibility would be:

- Use of smartboards: some smartboards have integrated OCR and its content can be accessed in real-time. Despite being an interesting approach, it can be expensive;
- Use of multimedia projector real-time collaborative text editors: instead of using the blackboard, educators can project documents and share them with learners using real-time collaborative text editors. The visually impaired learners would be able to access the content of the virtual 'blackboard' in real-time during the lecture.

Despite being useful for textual content, these approaches are not useful to graphical content, as discussed next.

C.5.0.3 Accessibility of Graphical Representations

According to the learners surveyed, the main challenge they faced was when graphical representations were used to convey and to discuss concepts.

These graphical representations often take the form of graphs (nodes and edges), but have peculiarities that result in complex graphical notations. Examples of this complexity include the UML class diagram and ERD, in which the inherent complexity of a node is often greater than that resulting from its connections, an unusual property for graphs.

These representations are inaccessible to visually impaired learners in their original format; they represent concepts and knowledge that can be conveyed to learners in different formats. The two most widely used approaches, both by educators and learners, were converting them to textual and tactile representations. While textual representations may consider only concepts, tactile representations often take into account graphical aspects. We have not found any empirical study that compares the effectivity of these approaches with experiments. Without this information, we could consider the usage of tactile maps as a normalization pedagogical tool, since it tries to just allow visually impaired learners to access graphical representations the same way sighted learners do. In other words, it does not take into account the mental model visually impaired learners create when interacting with graphical representations and how it could be represented in order to maximize their performance.

Regarding tools to make these representations accessible in real-time collaborative activities, such as in a classroom, there have been some recent researches that have delivered tools to support collaborative interaction between people with visual impairment and sighted people with graphical representations, some of them in real-time. Model2gether (LUQUE; BRANDÃO; BRANDÃO, 2016), CCmi (METATLA et al., 2012b), and (GRILLO; FORTES, 2014a) are examples of these tools.

Another aspect that represents a great challenge to inclusion, as cited by learners, is the availability of accessible books, as discussed next.

C.5.0.4 Accessible books

Without being able to access the same material available to sighted learners, it is not possible to offer equal learning conditions to visually impaired learners. The students answers indicate that, in most cases, only part of the official bibliography was made available in an accessible format.

Some approaches can contribute to changing this scenario. To understand these approaches, it is worth noting that many books, in different fields, do not have equivalent digital editions. This is the case of books published before the emergence of the digital book market.

To make already published non-digital material accessible to visually impaired learners, universities could have departments responsible for making material accessible. This is the case in many universities (DISABILITY..., 2018b; DISABILITY..., 2018a; DISABILITY..., 2018c). Using current high-speed scanning and quality OCR techniques, this is not as difficult as it used to be. This could also be a government initiative. The Brazilian government took this initiative regarding books used at lower education levels (MEC - Ministério da Educação, 2018). A partnership with representative societies of each field could result in a joint effort, which could be shared by public and private institutions, to produce a better result than each institution by itself. The most recent law related to the inclusion of individuals with impairment in society (Brazil, 2018a) does not require the existence of specialized departments with the aforementioned role.

For new books, a legislation to guarantee the publication of accessible editions of every published book would ensure accessible material for the future, since publishers have electronic versions of their books. While the article 68 of the Statute of People with Disabilities (*Lei Brasileira de Inclusão da Pessoa com Deficiência*) (Brazil, 2018a) specifies that the government must adopt mechanisms to promote the production, edition, and distribution of accessible books, it is still not mandatory in Brazil the publication of digital versions for new books.

C.5.0.5 Institution training

The lack of training was a concern for most educators, who do not have access to knowledge related to the inclusion of people with visual impairment in lectures. The inclusion in such cases depends only on the educator's initiative to search for approaches and tools that can help them during the process. It is more aligned with the normalization conception aforementioned. In some cases, the educator does not change his/her lecture style and just counts on the help of volunteer sighted learners or assistants to 'translate' what is being said into an accessible format. Again, the existence of departments specialized in accessibility in universities could contribute with training programs to educators. Furthermore, the inclusion of accessibility-related content in graduate courses to educators could also contribute to change the existing scenario.

There are some initiatives to offer courses related to accessibility that can be used by educators to compensate the lack of institution training. The University of Brasilia offers an open online course on accessible materials for the Moodle that can be accessed at <https://moodle.ead.unb.br>. Another initiative, by the UNICAMP - University of Campinas, is dedicated to specialized educational service educators, but it is only available to invited users, at <http://tnr.nied.unicamp.br/>.

C.5.0.6 Base of knowledge to inclusion

An initiative that could contribute to changing the inclusion scenario in Brazil is establishing an electronic base of knowledge, with scientific articles and tools, related to the inclusion of visually impaired learners in computing education programs. The United States, as an example, has a project funded by the government and maintained by the University of Washington, called Access Computing (University of Washington, 2018). It is a collection of resources to include learners with impairments in the computing field.

Currently, any Brazilian educator who wishes to include visually impaired learners in his/her class, has to conduct his/her own research to identify possible approaches to make this inclusion possible. If a central repository with such information were available, this could contribute to changing in this scenario.

C.6 Conclusions

This appendix presented the results of surveys conducted with visually impaired learners and educators in computing education programs.

In addition to educators and visually impaired learners, institutions and sighted students that take part in the inclusion process are important as well. This research does not present data related to these parties. While educational institutions could be surveyed, we understand that information gathered by educators and learners is more faithful, since institutions are obliged to offer minimal conditions to learners with impairments and admit the absence of these conditions could cause problems to the institutions. Regarding sighted students, there is no group or specific mean to find them. One approach to gather data about sighted students is to follow them during a course in which they have a classmate with visual impairment.

In our view, it is important to collect information about the inclusion of visually impaired learners in computing education programs to establish appropriate action plans by institutions, educators, and decision makers. We consider this work relevant in this context because the type of information present herein may guide and support the definition of procedures and policies to promote a more inclusive scenario.

Despite any effort by educators and institutions to promote a more inclusive scenario, most learners do not feel included at all.

The results indicate that further research and technological development efforts are required to produce a more inclusive scenario. A method to guide institutions, educators and learners in this scenario would be of great contribution to the field. We discussed some alternatives that could be adopted to produce this inclusive scenario.

APPENDIX D – USABILITY TEST FOR EXISTING UML TOOLS

In order to select participants for the usability test, we sent an invitation mail to a group list of blind developers (FORUM, 2018), which has more than 180 members with heterogeneous profiles, including computer students and professionals. We received 10 replies from group members interested in voluntarily participating in the test. As their previous experience with computers and screen readers was relevant to the reliability of test results, we asked them to respond to a questionnaire. The questionnaire was created and applied using Survey Gizmo (SURVEYGIZMO, 2018), an online survey tool accessible to people with blindness.

The questionnaire was composed of the following questions: (i) How many years of experience do you have as a computer user? (ii) How many years of experience do you have as a computer professional (system analyst, programmer, etc.)? (iii) What is your degree of visual impairment? (Sighted, Partially or totally blind)? (iv) Which screen readers do you use? (JAWS, Virtual Vision, NVDA, VoiceOver, SA or SAToGo, Windows Eyes, DosVox or other); (v) If you use more than one screen reader, which one do you use more often? (vi) How many years of experience do you have with the screen readers you use? (vii) Which operating system and screen reader are you going to use in the test? (viii) What is your knowledge about the UML?

Before starting the tests, we instructed the 10 volunteers with blindness to respond the questionnaire, but only 4 of them confirmed the participation. This number is reasonable when considering similar tests in the literature (BROOKSHIRE, 2006; GRILLO; FORTES, 2014b; LUQUE et al., 2014; OWEN; COBURN; CASTOR, 2014; SILVA; PANSANATO; FABRI, 2010). Reasons for the difference in number between the volunteers that responded the questionnaire and those that participated in the first phase could be the perception of a high workload to perform them. Therefore, we decided

to maintain the first phase of tests with the 4 users that confirmed participation and to conduct the second phase with other group of users composed by two computing professionals (1 with blindness and 1 sighted) that have been using UML and screen readers for several years. Table 49 presents the participants profile. A detailed version of this table may be found in Luque et al. (LUQUE; BRANDÃO; BRANDÃO, 2018).

In both test phases, we gave detailed instructions to participants about how to conduct the test with each tool. The instructions for the sighted participant were the same for participants with blindness and he conducted the tests with the monitor turned off to simulate blindness. Each participant was asked to build a UML class or sequence diagram, depending on the tool tested. We chose only these two diagrams to reduce the number of concepts that participants would have to manage during the test and because they are among the most used UML diagrams (DOBING; PARSONS, 2006).

We selected the sequence diagram for Diagrammr, jssequence-diagram, SeedUML, Seqdiag, and WebSequenceDiagrams because it is the only diagram they implement - considering the two aforementioned diagrams. Despite PlantUML and PlantTextUML Editor implement both class and sequence diagrams, the PlantUML web interface implements only sequence diagrams and, as PlantTextUML Editor is based on PlantUML, we also selected the sequence diagram to keep a common basis among them. ForUmple, MetaUML and yUML, we selected the only implemented diagram, class diagram - also considering the two aforementioned diagrams.

Similar instructions were prepared for the tools in which participants had to build sequence diagrams. Differences between these instructions and those for js-sequence-diagram, PlantTextUML Editor, PlantUML, SeedUML, Seqdiag and WebSequenceDiagram were related to the tool website, to links and buttons names, as well as to the DSL ¹ used to specify diagrams. The third question was asked only for Diagrammr, since other tools do not have a link/button to remove specific messages. The fourth question had to be slightly different because some tools have options to export the generated diagram as a SVG or JPG file.

For MetaUML, Umple, and yUML, we evaluated accessibility issues on building class diagrams. This time, the third question was the same for the three tools. As for

¹A DSL is a language developed for a particular computer application domain

Table 49: Participants' profile of the first user test.

Questions	Participants					
	Phase 1 (First Group)				Phase 2 (Second Group)	
	1	2	3	4	5	6
1 - Years of experience as computer user	20	12	8	13	20	10
2 - Years of experience as computer professional	8	0	3	5	13	0
3 - Do you have visual impairment? Partially Blind (PB)/ Totally Blind (TB)/ Sighted (SI)	TB	TB	TB	TB	SI	TB
...						
8 - Do you know the UML?	Yes	Yes	Yes	No	Yes	Yes

the tools we tested sequence diagrams, there is a difference between the DSL used in MetaUML, Umple, and yUML.

Threats to Validity

There were two main threats to the validity of the tests we conducted. First, there was a difference in the number of participants of the two test phases. Second, a sighted participant played the role of a person with blindness in the second phase. While we understand that this is not the best scenario, the sighted participant had been using screen readers for many years as an instructor of HCI