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KRDB Research Centre Technical Report:

Constraint-based Temporal Reasoning and E-Learning Tools for Deaf Users. A Literature Review

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Abstract

Good literacy, i.e. a reasonable ability to read and write, is essential for everyone. It ensures a continuous process of personal maturation and a positive social integration. Deaf children encounter several difficulties in learning to read and write due to their disability. New technologies can be usefully employed to create tools for supporting them in tackling this problem. Mich's PhD work is devoted to the design and the development of **LODE** (**LO**gic-based e-tool for **DE**af children). **LODE** is an e-learning application whose goal is to stimulate Italian deaf children to reason on temporal dimension of narrative texts. This reasoning process enhances children's ability to comprehend written texts. **LODE** proposes famous children's stories and interactive exercises. Its technological core is composed of a constraint-based temporal reasoner. This report aims to present a review of the scientific literature concerning the design, the development and the evaluation of **LODE**. It starts introducing some background information on automated temporal reasoning with constraint programming. Then, it provides some literature on problems encountered in reading and writing by deaf children. It goes on characterizing deaf users. General speaking, knowing the main characteristics of users is essential to design effective and efficient systems for them. The report ends with a short state of the art of e-learning tools for deaf or hard of hearing people. This review helps identify **LODE**'s strong points and drawbacks.

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Chapter 1

Introduction

This report aims to present a review of the scientific literature concerning the PhD research of Ornella Mich. The main focus of Mich's work is the design, the development and the evaluation of LODE (LOGic-based e-tool for DEaf children). LODE is an e-learning application whose main goal is to stimulate Italian deaf children to reason on temporal dimension of narratives. Deaf people often have problems in the comprehension of global relations, such as temporal relations, in texts written in a verbal language [9]. Reasoning on the temporal relation between two events of a story improves children's ability to comprehend written texts and produce effective written texts [17]. LODE proposes meaningful e-stories and interactive exercises. Its technological core is composed of a constraint-based automated reasoner. This module, not fully integrated yet, is going to be employed both for creating reasoning exercises automatically and for generating individual feedback from the exercise solutions proposed by the LODE user. For more technical details on LODE's architecture, on the implemented exercises and on the reasoner, see [35, 36] or try the LODE on-line demonstration [48].

Automated reasoning has been used in intelligent tutoring systems before. See WHY2-ATLAS, an intelligent tutoring system for qualitative physics [46], for example. But the LODE breakthrough is to apply automated reasoning techniques, in particular constraint-based reasoning, to an e-learning tool for *children*, which opens up some new possibilities.

LODE is a project that requires a multidisciplinary approach. Competences in computer science, in particular in automated reasoning and in interaction design, are involved; but also competences in linguistics, in psychology and in pedagogy are essential to create an effective and efficient tool. Obviously, this review does not pretend to be exhaustive. More work is required to cover all the scientific aspects that concern LODE.

This report is organized as follows. Chapter 2 introduces some background information on automated temporal reasoning with constraint programming. Chapter 3 provides the essential literature on problems encountered in reading and writing by deaf children. Chapter 4, after characterizing deaf users, analyzes, first, those usability issues that arise in the design and development of systems for deaf people; and then, it highlights the main problems encountered during the evaluation of software applications *for* and *with* deaf users. Chapter 5 presents a short state of the art of e-learning tools for deaf or hard of hearing people. Finally, Chapter 6 proposes some conclusive considerations.

Chapter 2

Constraint-based Temporal Reasoning

2.1 Time representation

Temporal dimension is a concept that children learn indirectly through narration [66]. Every text can be imagined as a representation of a chronological order of their world's events. The author decides the order to recount the events of a story. This order can be *natural* or *artificial*. It is natural when the textual order is equal to the real order; in this case, events are organized only with the operator *and then*. It is artificial when text redistributes the real events: it can, for example, put at the beginning of the text an event that in reality happens as the final one. In the case of artificial order, the operators used are *and before* or *and in the meantime*. Children learn the *and then* operator at around the age of four. They learn the *and before* operator at around the age of five to seven. They learn the *and in the meantime* operator last. Although children easily learn the *and then* operator, they need more time for learning the other operators. Telling stories to children is a way to help them learn operators that organize time [17]. This is why we decided to design LODE around famous children's stories. To assist the child in inferring the correct temporal relations between events in a narrative, LODE employs an automated temporal reasoner, namely, a constraint programming system.

Temporal Reasoning is a branch of Artificial Intelligence (AI) and involves the formal representation of time and a computational reasoning system for it. An instance of a temporal reasoning problem is given by the following exercise of LODE; the excerpt is taken from a simplified version of *The Ugly Duckling* by H.C. Andersen.

Mummy duck is sitting on some eggs: she has five eggs, four are small, and one is big. All of a sudden, while she is still sitting on eggs, the small eggshells crack and four little yellow ducklings peep out. Mummy duck watches the big egg but sees no signs of cracking. . . So she decides to keep on sitting on it. After some days, while she is sitting on it, the big eggshell also cracks and an ugly gray duckling peeps out. . .

A question concerning two temporal events of this story could be: "Do the small eggshells crack before the big eggshell cracks?". Answering such a question means solving a temporal reasoning problem; solving it in an automated manner means choosing a formal representation of time and a computational automated reasoning system for it. Here we adopt intervals as the primitive entities for representing time dimensions; each interval is uniquely associated with a time event. Between any two pairs of events, there is an *atomic Allen* relation [4], namely, a relation of the form

before, meets, overlaps, starts, during, finishes, equals

or rel^{-1} , where rel is one of the above relations and rel^{-1} is the *inverse* of rel .

2.2 Constraint Programming for Automated Temporal Reasoning

Constraint programming is an embedding of constraints in a host language [6]. It originated from the logic programming community and has become a flourishing programming paradigm implemented in a number of heterogeneous environments, e.g., B-Prolog [12], a proprietary Prolog-based Constraint Logic Programming (CLP) system, ECLⁱPS^e [8, 25], an open-source CLP system, or GNU Prolog [37], a free Prolog compiler with constraint solving over finite domains. CLP technology is expressive: it enables a declarative solution with readable code. The efficiency of eight CLP systems are compared in [31], where their strengths and weaknesses are indicated.

The central notion of constraint programming is that of constraint, i.e., a relation, involving finitely many variables each ranging over a domain of possible values. Even if constraint programming was successfully used in several modeling applications (see for example [14, 20, 33]), from our study it seems that LODE is the first attempt of applying it in the e-learning field.

Given a problem, e.g., the temporal problem above, the constraint programmer formalizes it as a *constraint problem*, which is given by

- finitely many *variables*, x_1, \dots, x_n ,
- each ranging on a *domain* D_i of values (infinite or finite),
- and a set of *constraints*, namely, relations of the form $C \subseteq D_{i_1} \times \dots \times D_{i_m}$.

Once the temporal reasoning problem is formalized as a constraint problem in a suitable programming language, e.g., CLP (Constraint Logic Programming), it can be solved by invoking a constraint programming system, e.g., ECLⁱPS^e; see [7, 8]. For instance, ECLⁱPS^e can be invoked to solve the following tasks for us: to decide on "the big eggshell cracks after the small eggshells crack"; to produce all the Allen relations between the events "the big eggshell cracks" and "the small eggshells crack", implicit in the problem and consistent with it. For a survey on temporal reasoning and constraint programming, we refer the reader to [34].

Chapter 3

Literacy Issues and Deaf People

3.1 How deaf people learn to read and write

Learning to read and write effectively is an extremely difficult task for people that were born deaf or hard of hearing. As they have no access or a very partial access to the verbal language in its spoken form in their first years of life, they lack the primary, natural means of acquiring literacy skills. ‘Deaf children have unique communication needs: unable to hear the continuous, repeated flow of language interchange around them, they are not automatically exposed to the enormous amounts of language stimulation experienced by hearing children’ [72].

Research carried out on deaf subjects in Italian and English speaking countries point out that deaf people rarely achieve verbal language literacy, as demonstrated by the common mistakes traced in their written productions [27]. Their vocabulary is rather poor and characterized by lexical rigidity. They typically write short sentences and employ very simple syntactic structures; relative, subordinate and pronominal clauses are problematic for them, e.g., “the dog chased the girl had on a red dress” omitting “who”, reported in [19], p. 82.

Given that information interchange via language is scarce in the first years of life, deaf people also seem to have problems in expressing global relations, formulating hypotheses and drawing inferences in verbal Italian. A reason for these difficulties regarding textual organization and conceptual coherence can be traced to their “poor knowledge of linguistic structures for verbal and written language” that “may interfere with their ability to organize ideas conceptually when producing [oral and] written narrative discourse” [9]. Obviously enough, this problem also involves the global comprehension of written texts to the effect that their reading ability does not often go beyond that of a eight-year old child [63].

Linguistic education of deaf children may follow the *oralist* method or the *manual* method. Oral education aims at educating deaf children in such a way that they will be integrate with the majority culture of their country. It is based on the use of coclear implantation and lip reading. Manual education is sign language based: it generally aims at introducing deaf children into the Deaf Culture. Sign, when used appropriately, forms a beautiful and expressive way of communication for deaf people [65]. The spread of sign languages favored the enrichment of Deaf culture. However, it is essential that deaf people also learn to read and write a verbal language to

be socially integrated in the community where they live [58]. Recently some schools introduced a new educative method, the bimodal method, based on both the aforementioned ones. See the experience of the Cossato elementary school in Italy for example [69]. These types of schools propose educational programs that intend both to integrate deaf children in the language and culture of hearing children and to integrate hearing children in the language and culture of deaf children.

Given that limited literacy skills is not only an obstacle to the plain integration of deaf minority into our society, but also a limitation to the complete development of each deaf child as a human being [16], our purpose is to develop an e-learning tool for deaf children tackling the comprehension of global relations in narratives written in verbal Italian. More specifically, LODE deals with global temporal relations.

3.2 New technologies and deaf people literacy

New technologies in general, Artificial Intelligence (AI) methods and tools, in particular, can really innovate the world of learning for people with disability. To exploit these opportunities fully dedicated university educational programs [50] and several international conferences have been organized [11, 41].

New technologies offer great opportunities for hearing-impaired children. Current research in computer science seems mainly to focus on applications related to sign language, such as LIS, for its transcription, writing, recognition and teaching see [13, 54]. Considerably less attention seems to be devoted to the development of e-learning tools for improving the literacy of deaf children. Our first analysis of the scientific literature confirmed our impression: we could only find references to eight e-learning applications of this type currently available in Italy and few projects abroad.

In the Chapter 5 we overview these e-learning applications. Unfortunately, we could not find an assessment of each application's effectiveness with respect to its goals. Therefore, ours is not a technical review; rather, it is a compact description of those tools and their respective aims.

Chapter 4

Usability and Deaf People

4.1 Deaf user characterization

Deaf users are not an undifferentiated group of users. Indeed, there are different types and different degrees of deafness. Deafness can be conductive or sensorineural. Conductive deafness is a form of deafness that results from a blockage of the ear canal or dysfunction of the ossicles or eardrum (sound collecting apparatus) [23]. In conductive hearing loss the auditory nerve is normal, but there exists a physical problem with the sound collecting apparatus. Sensorineural deafness is an irreversible type of hearing loss that occurs when cochlear sensorineural elements or the cochlear nerve is damaged in some way [53]. It can progress to total deafness. Sensorineural deafness can be treated with hearing aids or cochlear implants in most cases [49].

There are basically four degrees of deafness: mild, moderate, severe and profound. Even a mild hearing loss can be serious for children still learning to talk. With a severe degree of deafness there is a lot of difficulty hearing speech. It is at this level that we begin to use the term *deaf*. With profound deafness, hearing aids may or may not help; cochlear implants are often an option.

Communication abilities of deaf people depend also on the age they become deaf. The situation of a child who was born deaf or who lost their hearing prior to the age at which speech is acquired (prelingual deafness) is completely different from that of a child who became deaf when she/he was older (postlingual deafness). Prelingual deaf children are (often) socially isolated and unable to pick up auditory social cues, especially if they have hearing parents that are not able to communicate with her/him by means of sign languages. This can result in a deaf person becoming generally irritable. *When a person is prelingually deaf, they learn a spoken language mainly through an artificial means, i.e., reading. Because print does not convey as much language information that sound conveys, prelingually deaf persons are deprived of auditory language input. The result is diminished reading and writing skills* [51].

Deaf people are visual learners, that is they learn information best by seeing it. Their eyes are the most important senses for learning. *Visual learners prefer using images, pictures, colors, and maps to organize information and communicate with others. They can easily visualize objects, plans and outcomes in their minds eye. They also have good spatial sense, which gives them a good sense of direction. They can easily find their way around using maps, and they rarely*

get lost [47]. Different teaching strategies, engaging also the brain right hemisphere, should be applied for visual learners [38].

4.2 Designing for deaf children

New technologies are often complex to use for their intended users. Designers and developers may be supported in the creation of usable tools by the Interaction Design (IaD) discipline. IaD is *the discipline of defining and creating the behavior of technical, biological, environmental and organizational systems.[...].Interaction design defines the behavior (the "interaction") of an artifact or system in response to its users over time.[...]* Interaction designers are typically informed by user research, design with an emphasis on behavior as well as form, and evaluate design in terms of usability and emotional factors [43]. The aim of IaD is, on the one hand, to minimize the time new users should have to spend to learn how to use new tools; on the other hand, to increase the efficiency of the tools.

IaD's rules affirm that the design should be a step by step process, that is it should proceed by sequential iterations. The idea behind IaD is to create quick prototypes and test them with the users to make sure the proposed solution is the right one. After this first step, designers improve the prototype following user's behavior and observations during the test. Background principles of IaD are provided by cognitive psychology [21, 61].

Users are a fundamental factor in the IaD process. *To create a good product, it is critical to understand its users* [32].

The unique characteristic of deaf users and the high variability inside this group of uses requires sensitivity and special attention in designing systems for them. Specific usability and accessibility rules should be followed. In the design of the user interface of e-tools to be used by deaf people, the visual input should always augment or replace the auditory input [15, 40]. Moreover, captions must be provided with all multimedia presentations and all visual cues must be noticeable even if the user is not looking straight at the screen [40].

According to some research findings [52], deaf and hearing people encode information differently, with different strategies in the organization and access to knowledge stored in the work and long term memory. Moreover, because deaf people seem to focus mostly on concept details and images rather than on relations among concepts when processing information, the use of graphics and hypertext in e-tools for deaf people should match such learning strategies [29]. These differences must be also considered when developing web systems for deaf people.

Last but not least, LODE is for children, thus graphics plays a relevant role in it; yet, non-standard interaction techniques cause predictable problems in hypertextual user interfaces, lack of perceived clickability affordances, such as overly flat graphics, cause users to miss features because they overlook links [30].

If we also consider that LODE's users are children, the aforementioned usability problems are amplified: as Nielsen says [60] "the idea that children are masters of technology and can defeat any computer-related difficulty is a myth. [...] Poor usability, combined with kids' lack of patience in the face of complexity, result in many simply leaving websites".

4.3 Systems evaluation with deaf users

The evaluation phase is extremely important for getting to an effective and efficient application. First of all, it is essential to start with a clear experimental design [71]. Then, the right statistics must be applied in order to be able to deduct the correct results [73].

Testing software applications *for* deaf users *with* deaf users requires specific methods and procedures, unless the evaluation is simplified testing the system not with deaf users, but with hearing adult experts [1]. Another procedure is that of involving deaf children, their parents and their therapists in the experiment [70]. In this case, the influence of the presence of teachers and/or parents on the procedure must be observed in detail [26].

When evaluating systems with deaf users, several methods for usability testing [39] cannot be directly employed. For instance, due to the aforementioned literacy problems, traditional inquiry methods based on questionnaires are rather impracticable. Also methods based on oral interviews directly to deaf users are obviously not viable. One approach consists of doing indirect interviews through parents or interpreters; however, this approach could easily lead to imprecise results. In general, it is important to describe what it is like to participate in a usability test to the session participants before starting the test [39]. In the case of deaf users, it is not always possible for test designers to communicate directly to participants, and interpreters may misunderstand the explanation of the test procedure. Therefore, the most viable approach seems to video users during the test and to record their actions on a log file. However, new testing methods must be designed for performing more reliable usability tests with deaf users.

Last but not least, recruiting deaf users willing to test e-tools for them is another main problem; deaf people are usually widely spread throughout the country, and, due to a long history of isolation, they generally tend to be distrustful of hearing people [45].

Chapter 5

E-learning tools for deaf children: the State of the Art

5.1 Italian Tools

Three systems were developed in between 1997–1998 to overcome specific problems with verbal Italian grammar:

- *Articoli* [10], which aims at teaching Italian articles and their use, including gender agreement;
- *Carotino* [18], an interactive tool for teaching simple Italian phrases; the child is shown an image (e.g., a flower) and is prompted with simple questions such as what-questions (e.g., “what is it?”); whenever the child writes a grammatically incorrect answer, he or she is invited to reformulate it;
- *Pro-Peanuts* [64], which aims at teaching the correct use of pronouns.

Furthermore, we have found references to a tool developed in 1994, *Corso di Lettura* [24]; according to its specifications, the tool aims to improve the reading capabilities of hearing-impaired children.

In order to facilitate the integration of a deaf girl into an Italian primary school, teachers and students of the school created *Fabulis* [28], a collection of famous fables for children narrated using text and images, based on gestures and LIS signs.

Another application born in a school is *Nuvolina* [62], the result of a project realised in a fourth class of an Italian primary school. Also in this case, the project aimed at integrating a deaf girl into the class. *Nuvolina* is a multimedia tale with contents in written and spoken Italian, English and French. The version in verbal Italian is also presented in LIS by means of short videos.

Another bilingual tool is *Gli Animali della Savana* [5], a piece of multimedia software based on text, images and videos, featuring an actor who translates the written text in LIS. Assisted by a

lion cartoon, the user navigates through a series of pages presenting the life of 10 wild animals. The child can also answer questions and record his or her notes on a personal notebook page.

A more recent and ambitious project is *Tell me a Dictionary* [68, 44], the purpose of which is to offer both deaf and hearing children an interactive and enjoyable instrument to discover and compare two very different languages, LIS and Italian. *Tell me a Dictionary* is a multimedia series of six DVDs and books. The vocabulary is presented “through stories and sentences that project both languages as living languages, thanks also to a lively 8-minute animated cartoon, signed and spoken narration, Italian with subtitles, vocabulary building games and a glossary that takes you back to the vocabulary items in the DVD” [44]. The first volume is the only one that has been developed so far and which is currently in use.

	<i>Content type</i>	<i>Use of sign language</i>	<i>Dialogue interface</i>	<i>Reading comprehension</i>	<i>Active feedback</i>	<i>Grammar analysis</i>	<i>Speech recognition</i>	<i>Global reasoning</i>
Articoli	exercises	no	no	no	no	no	no	no
Carotino	exercises	no	no	no	no	no	no	no
Pro-Peanuts	cartoons	no	no	no	no	no	no	no
Corso di Lettura	exercises	no	no	yes	yes	no	no	no
Fabulis	children’s stories	yes	no	yes	no	no	no	no
Nuvolina	a tale	yes	no	no	no	no	no	no
Gli animali della Savana	Exercises	yes	no	no	no	no	no	no
Tell me a Dictionary	cartoons	yes	no	no	no	no	no	no
ICICLE	user’s input	yes	yes	no	yes	yes	yes	no
Corner Stones	children’s stories	yes	no	no	no	no	no	no
FtL	interactive books	no	yes	yes	no	no	yes	no
LODE	children’s stories	planned	yes	yes	yes	planned	no	yes

Table 5.1: Tools for literacy improvement: a comparative synthesis

5.2 Non-Italian Projects

In this section we introduce some non-Italian projects which aim at improving the literacy of deaf or hard of hearing children in the verbal language of the country of origin: ICICLE [42, 57], CornerStones [59] and FtL [22]. The goals of these tools are closer to those of LODE. This section mentions another system, SMILE [2, 3, 67], which is actually not an application for helping deaf children to improve their reading and writing ability. Indeed, it helps them learn math and science concepts. However, SMILE is mentioned due to its innovative interface for deaf children, based on virtual reality.

ICICLE (Interactive Computer Identification and Correction of Language Errors) [42, 57] aims at tutoring deaf students whose native language is American Sign Language (ASL). ICICLE has developed from the NLP/AI Group at the CIS Department of the University of Delaware, USA. The primary goal of the ICICLE researchers was to employ natural language processing and generation to tutor deaf students on their written English. ICICLE's interaction with the user takes the form of a cycle of user input and system response. The cycle begins when a user submits a piece of writing to be reviewed by the system. The system then performs a syntactic analysis on this writing, determines its errors, and constructs a response in the form of tutorial feedback. This feedback is aimed towards making the student aware of the nature of the errors found in the writing and giving him or her the information needed to correct them. ICICLE's research areas include: the development of the user model [55, 56]; the use of machine learning to train a text planning model to replace the canned explanations; the implementation of a dialogue interface; the development of a spell checker algorithm with rules modified by those in the program *aspell* in order to capture the unique spelling behavior of the user population; the integration of explanatory material as video-recorded ASL performed by an ASL interpreter, and the investigation of "signing avatars" to incorporate sign language instructions generated by the tutorial component of the system.

CornerStones is a project developed at the Carl and Ruth Shapiro Family National Center for Accessible Media (NCAM), a research and development facility dedicated to the issues of media and information technology for people with disabilities in their homes, schools, workplaces, and communities. It is a technology-infused approach to literacy development for early primary children who are deaf or hard of hearing. Academic experts in literacy and deafness, along with teachers of deaf students participated in its development. An essential element of Cornerstones is a story taken from the PBS's literacy series *Between the Lions*, complemented by versions of the story in American Sign Language and other visual-spatial systems for communicating with deaf children. Cornerstones developers evaluated their system with children and teachers and results of their evaluation demonstrated an increase in students knowledge of selected words from pre-test to post-test.

Another interesting project aiming at improving students' literacy is the Foundations to Literacy (FtL) project, developed at the Center for Spoken Language Research (CSLR, University of Colorado) in collaboration with other research centres. FtL (Foundations to Literacy) has been developed at the Center for Spoken Language Research (CSLR, University of Colorado) in collaboration with other research centres. It has not been developed for deaf or hard of hearing children, but this type of users has also been considered. FtL is a comprehensive computer-based reading program that has been designed to teach beginning and early readers to read with good comprehension. FtL consists of three integrated components: a Managed Learning Environment (MLE) that tracks and displays student progress and manages an individual study plan for each

student; Foundational Skills Reading Exercises, which teach and practice basic reading skills, such as alphabet knowledge and word decoding, providing the foundation for fluent reading; Interactive Books, which represent the state of the art in integration of human language and animation technologies to enable conversational interaction with a Virtual Tutor that teaches fluent reading and comprehension of text. The final evaluation of FtL produced significant learning gains for letter and word recognition for kindergarten students.

SMILE (Science and Math in an Immersive Learning Environments) is a project aiming at developing an immersive virtual learning environment (VLE) in which deaf and hearing children (age 5-10) interact with fantasy 3D avatars and objects and learn standards-based math and science concepts, and relative American Sign Language (ASL) terminology. The virtual world includes a series of stores in which the participants perform hands-on, minds-on math/science activities based on the standard elementary school curriculum. Users have the ability to explore the stores, select and manipulate objects, and communicate with the virtual store keepers in spoken and written English, and American Sign Language. Actually, SMILE is not a specific tool for teaching reading and writing to deaf children, but we cited it here due to its innovation: SMILE is the first bilingual VLE for deaf and hearing students proposing learning activities that are grounded in research on effective pedagogy. Moreover, it proposes a sophisticated application of VLE: this approach could be successfully employed for developing new effective tools for improving also literacy of deaf children.

	<i>Look&Feel</i>	<i>Embodied agent</i>	<i>Navigability</i>	<i>On the Web</i>	<i>Specific For Children</i>
Tell me a Dictionary	very good	no	good enough	no	yes
ICICLE	traditional	to be done	good for adults	no	no
FtL	not known	yes	not known	no	yes
MAS	traditional	no	good for adults	no	no
SMILE	virtual reality	yes	with some problems	no	yes
LODE	plain graphics	no	easy	yes	yes

Table 5.2: GUI Aspects of four main applications

5.3 Comparison

According to our survey of Italian and non-Italian projects for deaf children, LODE is the first Web-based e-learning tool tackling literacy issues of deaf children which goes beyond the syntax and grammar of the verbal language of the country of origin; in fact, LODE aims at stimulating global deductive reasoning—in particular temporal reasoning—on narratives. This is a distinguishing feature of LODE that is made possible through the use of an automated reasoner in the form of a CLP system, namely, ECLⁱPS^e [8]. Table 5.1 offers a comparative analysis of LODE with the principal and assessed tools for the literacy improvement of deaf children. System *educative aspects* are considered in this table. Table 5.2 offers a summary of the *interface aspects* characterizing some of the aforementioned systems: Tell Me a Dictionary, ICICLE, FtL and SMILE. In this table, we consider only these four applications because they are the most complete and those that propose the most innovative interfaces.

Chapter 6

Conclusions

This report aimed to present a review of the scientific literature concerning the design, the development and the evaluation of LODE, an e-learning tool for deaf children. LODE is the main focus of the PhD research of Ornella Mich.

LODE's project is a multidisciplinary task that requires competences in different scientific fields, as outlined in Chapter 1. This review did not wish to be an exhaustive study. However, it tried to touch briefly all the scientific aspects that concern LODE. After introducing temporal reasoning with constraint programming, it provided the essential literature on literacy and deaf children. Then, it characterized deaf users and analyzed those usability issues that arise in the design and development of systems for deaf people. It also presented the main problems encountered during the evaluation of software applications *for* and *with* deaf users. At the end, it concluded with a short state of the art of e-learning tools for deaf children.

Interesting points came up during this study. To summarize, it showed, first, the breakthrough of using constraint programming for improving an e-learning tool for children. Secondly, it confirmed that new technologies can make the difference, when correctly designed, in the education of deaf children. And finally, it highlighted the lack of specific research on methods for testing usability of tools for deaf users.

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