Pedagogical Architecture – Internet Artifacts For Bilingualism of the Deaf
(Sign Language/Portuguese)

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Abstract

Deaf children born to non-Deaf parents have little to no exposure to Sign Language acquisition. Sign Language, the natural language of the Deaf, is a complete linguistic system, different from the oral language; and it is necessary for intellectual development. There is a lack of educational tools for/in Sign Language and few researches to inform designers on how to build computational tools to provide the Deaf children and their parents with Literacy: the effective appropriation of knowledge, via bilingualism. Such goal can be achieved by the use of Sign Language as the first language for the Deaf and as a second language for the parents; and by the use of the written modality of the oral language for the Deaf. This paper presents a pedagogical architecture and a computational process that allows for scientific-based design of Artifacts. A case study is presented to discuss the development of a prototype.

1. Introduction

Over 90% of Deaf children are born to non-Deaf parents, according to the OMS [1], which results in little to no exposure to Sign Language (SL), the natural language of the Deaf. Fernandes [2] tells us that the lack of early SL acquisition and consequent language barrier within the family prevents the Deaf children to have full access to available human possibilities such as intellectual development, communication, and citizenship. Action is needed to address such issues, with adequate e-learning tools for/in SL.

The goal of literacy for Deaf children and their parents is still elusive in schools. Literacy is the resulting process of appropriation and use of language and its meaning via bilingualism. Bilingualism is the movement that holds SL as the natural language for the Deaf, and the written form of the oral language (Portuguese, in our case) as the second language [2].

Unfortunately, there are very few attempts at e-learning tools for literacy and bilingualism in/or for SL for Deaf children [2]. Pedagogical Architectures (PA) have been shown to incorporate an understanding of how to help learners modify their cognitive structures, a necessary feature in Deaf children education. PA can be defined as learning structures that combine different components, articulated from pedagogical, technological and political approaches. Carvalho, Menezes & Nevado [3] show that PA are extensively used in several educational areas. But they come short of informing the design and implementation of tools.

This paper presents a PA for Deaf literacy. The proposed PA is based on one of the SL features: its iconicity. It incorporates the use of cognitive theories (e.g. Conceptual Maps) for mind development. Additionally, It also presents a computational process to inform designers in their tasks of implementing computer-mediated tools. A case study shows the use of the PA, and discusses the prototype of an Artifact for Bilingualism of the Deaf (in SL/Portuguese) developed as per the proposed process. Initial results show adequacy for both members of the community, educators, and for computer scientists. The remainder of this article briefly discusses the Deaf issues related to Literacy and SL in Section 2. Section 3 presents the PA and its components. Section 4 shows some related work. Section 5 presents a computational process on how to implement the PA. Section 6 presents a case study.

2. Deaf issues

2.1. Diminished capacities

For Chomsky [4], the ability to understand, create and transform culture is a human trait that is language-dependent. Kyle [5] tells that the gaps between the Deaf and her family, due to the lack of communication, are the cause of high levels of mental diseases later in the Deaf’s life, in direct relation to life and survival of the Deaf.

Brito [6] tells that without SL acquisition, the Deaf has a diminished ability to perform tasks for the development of intelligent action: the Deaf does not learn how to plan and how to overcome impulsive action; the Deaf does not become independent of the
visual, concrete situation and the Deaf has difficulties to control herself and to socialize. Consequently, members of the Deaf community are more likely to suffer from: the lack of meaning and knowledge creation; the lack of identity and cultural diversity; the lack of intellectual development, among others, says Finau [7]. All of these predicaments are dire consequences caused by the lack of affective ties of the human being with language. Due to this language barrier, the non-Deaf parents encounter difficulties to teach their Deaf children even the basics, such as personal hygiene etc. Deaf parents have no baby device (electronic baby sitter) to warn them in their sleep when the child is crying.

Mostly, the Deaf encounters difficulties to perform tasks of daily life: to obtain general information, such as public transportation information; to make medical appointments; to shop for medication on drugstores etc. For instance, consider a scenario where people in a public space (e.g. a subway station) are warned about a train delay, or change of station, or even if the fire alarm sounds: the Deaf will see everyone leaving and not know the reason and what actions to take. Many a young Deaf have been harassed because the use of SL was mistaken as an insult.

Society, on one hand, has little to offer the Deaf; on the other hand, there are special reserved parking spaces, ramps, special cars, Braille written material, companion dogs, software that accepts voice command and that “reads” screen text. There are all other sorts of aids (technical or not) for people with deficiencies and their needs. This research calls attention to the need to offer equivalent opportunities for the Deaf. Skliar [8] tells that the Deaf are not defined by deafness, but rather by a culture, and SL is a major part of the Deaf Culture: a term applied to the social movement that holds deafness to be a difference in human experience (which includes the right to use SL) rather than a disability.

2.2. Literacy

For Sánchez [9], language is more than a way of communication, and it includes a regulation function of thought, according to Vigotsky [10]. Bilingualism, considered to be more adequate for Deaf education, is the movement that claims the use of, at least, two languages: SL, as a first language, and a second language in its written form – in our case, Portuguese, the oral language of Brazil [9]. The written form of the oral language can be achieved because the development of writing is independent from the oral language, given that it is a different system, both in structure and behavior [10].

For Lévy [11], society must go beyond the mere use of computers for games and leisure, thus limiting its use. This is a clear call for an innovative, intellectual, interactive use of technologies: to make sense of the world, the child must be able to construct her own mental models of interactions, and, for such, e-learning tools (that scaffold this process) are needed: “new intellectual technologies” that are to be used for Literacy.

Literacy is the resulting process of social practices of the use of the written form of the oral language as a symbolic system and as a technology, in specific contexts, for specific goals (in our context, to be acquired by the Deaf by a functional use of the language, where the language assumes a character of real meaning). “Therefore, Literacy as effective appropriation is pleasurable, is leisure, is access to information, is communication, is a way to exercise citizenship in different social practices” [2:131].

2.3. Sign languages

Since Stokoe [12], Sign Languages (SL) are considered a legitimate, complete linguistic system, of gestural spatial-visual manner. Languages are social constructs that reflect in the identity of a certain group, and serve many functions and purposes, other than communication (e.g. modeling the world). SL are fully conventionalized, with rules and structure capable of providing the Deaf with an adequate means to realize all of their linguistic potentialities [2] [12]. They are not universal (i.e. each country has its own SL). They are not mere mimics. They are not gestures. They are independent from the oral language. Formal language traits start a chain of variable patterns of development in second language acquisition according to Sales [13]. This way, one is capable to associate SL acquisition to universal language acquisition and meaning attribution of the type IF a THEN b. Additionally, SLs are iconic (i.e. they possess an interactional property defined by humans, derived by the similarities between a linguistic form and its meaning). Iconicity is a formal part of SL grammar and its lexicon, and will serve as the basis for the proposed PA.

3. Pedagogical architectures for literacy

3.1. PA overview

PA are teaching and learning structures that are articulated around pedagogical, technological and political dimensions. PA should be used to design educational tools that go beyond the mere transmission of knowledge, towards providing an environment for
the construction of the world (via communication and disturbances on the signification system of the student). This construction should be achieved by enticing cognitive activities for the development of interactive work: a continuous process based on the action of the subject over the world, and the elaboration of such action in order to comprehend the world and herself [3].

Subjects dynamically derive meanings when they partake in the process of ample interaction. PA are threefold: First, PA should have a strong pedagogical conception (e.g. Piaget’s [14] education to: find solutions to real-world problems; transform information into knowledge; authorship, expression and interlocution; investigation and innovation; autonomy and collaboration – i.e. to cooperate in the action; to operate in common). Second, PA should also have a methodological systematization: seductive and interactive cognitive activities (e.g. projects, problem-solving, simulated actions etc.). Finally, PA should provide a virtual learning environment.

The proposed PA is to be used for the development of internet-based e-learning tools for Deaf Literacy. It incorporates features required by Interactive Learning Environments (ILE) according to Schneider et al. [15:1]: “the multiplicity of teaching styles (the learning content may be taught in several ways), the multiplicity of learning sources (experience, coaching, hypertext browsing), the use of a rich interface allowing for complex problem situations and for supporting pedagogical reasoning”.

Collaborative online systems over the Internet are powerful tools to aid Deaf Literacy. Collaborative interactions are relevant for human, social, historical and political formation of the individual, and may aid in the creation of the Deaf’s identity and overall development. Aecoverde [16:3] tells us that activities mediated by computer systems scaffold the sharing of social languages, and they provide an arena where “[...] the ties established form the dialogic and ideological ties needed for the multi-lingual encounter of utterances, voices, intonations, themes and points-of-view, thus creating a new space for social interaction for the Deaf”.

Guimarães et al. [17] presents a conceptual meta-environment framework for Deaf children literacy, called Intellectual Interactions (II) to construct computational Intellectual Artifacts to promote bilingualism (SL/Portuguese). It is a complete PA, according to Behar, Bernardi & Silva [18] and, additionally, it presents a computational process to help stakeholders design the Artifacts.

**3.2. PA organizational and instructional elements**

**Organizational elements**: its objectives address the demands of the Deaf communities in its want for Literacy, in the form of products, validation, and a process to build Artifacts. Literacy is the great area of knowledge to be contemplated, in a social-interactionism pedagogical approach (a process of interactions inducing the relationship between actions and representations, where knowledge is something that stands in the interaction between the subject and her environment). Additionally, the II process provides stakeholders with a comprehension of time and space with respect to the construction of knowledge using “Spontaneous Concepts” (i.e. those required in the daily concrete experience, sensorial in nature) in order to help the child to develop “Scientific Concepts” (i.e. more abstract, not mandated by the concrete only, more rational, acquired by explanation, related to previous knowledge and concepts) from Vigotsky [10].

The resulting Artifact should reproduce the social insertion environment of the subjects, in situations drawn from the real world, for SL acquisition and for intellectual development. The stakeholders have the following profile: students: Deaf children (of various ages and degrees of development) and their non-Deaf parents – being that they are novice in the use of SL. The collaborative/interactive tool to be used will focus on SL.

As for the **Instructional elements**, II provides flexibility for the designers to build different genres (games, stories, learning objects (LO), educational software, narratives, storytelling environments etc.). It also allows for various teaching/learning styles such as free discovery (Papert), guided discovery (Piaget), apprenticeship (Vigotsky) and others. Since each model is concerned with mostly only one aspect, an educational computing system should account for a combination of theoretical bodies of knowledge, each one linked to some aspect of real world, considering that all of them may be present at some stage of learning according to Schneider et al. [15].

**4. Related work**

Existing technologies (e.g. PA and their related LO and Artifacts) are inadequate to the Deaf’s specificities (i.e. they are not in Sign Language); they lack usability for the target audience; they do not allow for multiple and full collaboration; they are not designed for Literacy as per the needs of the Deaf. Mostly, they do not present stakeholders with a process for computational development of ILE, tools and Artifacts, the focus of this paper.
Amongst the surveyed PA that are not geared towards Literacy, Deaf issues, SL and the target audience (namely Deaf children and non-Deaf parents) we suggest the following, for their potential for knowledge creation: Elia & Sampaio [19] present an interactive computational platform that presents the student with modules containing topics of a given subject, in instructional or task format, with evaluation of learning and bibliographic references. Fagundes et al. [20] present a non-computational learning project: an initial brainstorm collects the questions of interest, which are then grouped. Previous knowledge is used to explore the questions based on provisional certainties and temporary doubts. The collaborative process addresses the questions and the final stage consists of providing answers. Serres & Basso [21] present Virtual Diaries, a communication channel between students and the teacher for mentoring, additional teaching etc.

As for those PA that are somewhat related to Sign Language, we find several inadequacies: Silva [22] presents a web-based one-to-one vocabulary Portuguese/SL, with emphasis on hand configuration and non-manual expressions only; leaving out several other aspects of SL, writing, acquisition etc. It assumes that the student knows Portuguese. Secco & Silva [23] present an environment in SL, based on a Problem-Based Learning strategy to teach SL. But it presupposes that the Deaf already knows SL (a strange contradiction).

Tavares et al. [24] present a sensor-based device that captures the movement and sends the data to a software that “translates” it into SL. The use of a glove makes it awkward (imagine a voice recognition system that requires the user to wear a glove on her tongue). Although it claims to teach Portuguese and SL, it is not clear how that would happen.

As for general tools, the market is flooded with attempts to treat SL. Those attempts are not educational-oriented, and fail mostly due to wrongful approaches (e.g. one-to-one translation; limited vocabulary, lack of usability etc.): Coradine et al. [25] show a system that recognizes voice and synthetizes in SL via Flash animations: it is restricted to a few lexical items and expressions; and it presupposes the use of the oral language. A system presented at BBC [26] proposes to translate voice to British Sign Language 3D avatar. SignSmith [27] proposes an environment for the creation of 3D avatars (without providing the actual links to SL/avatar). iSign [28] presents a “dictionary” with an animated avatar (that is, again, a one-to-one oral language to SL “translator” – it requires the knowledge of the oral language). AcceleGlove [29] presents yet another glove to translate the alphabet (it is restricted to the “spelling” used by the Deaf-mute - a Deaf person is not always mute). SL is not a “spelled” version of the oral language. There is no clear indication of how the Artifact will achieve the proposed teaching of SL.

5. Computational Process

As pointed before, most PA are not designed as to have the necessary operationality demanded for implementation. Hence the need for a process that will make the PA more relevant to computer scientists. The use of II process not only translates concepts into design terminology, but it adds some components of pedagogical strategies to be used to achieve Literacy. The remainder of this section outlines each component of the II process.

5.1. Intellectual Interactions

The II process ties the structure of learning environments to existing models of cognitive development, which can be implemented into Artifacts. Most theories address only a specific facet of Literacy, thus, their combination allows for the design of a more complex, global learning environment. As seen in Figure 1, the II process combines the prominent iconicity of SL with cognitive theories in a conceptual model to inform design of Artifacts for bilingualism Literacy.

Figure 1. Intellectual Interactions Uses

Figure 2 shows the stakeholders and the overall use cases of the II process. The overall process is comprised of Designing, Implementation and Use of the Artifact. The Design of the Artifact is comprised by activities to create the object, the knowledge base and the intellectual interactions. Thus, the Artifact can be created by developers, and used by educators, along with Deaf children and their parents, for literacy purposes. Figure 2 shows that the process contemplates several stakeholders and activities to be performed for the design of the computational tools.
5.2. Stakeholders

Stakeholders have the following profile: Deaf children (of various ages and degrees of development) and their non-Deaf parents – being that they are novice in the use of SL. Knowledge Managers are the specialists and the educators. They will guide the selection of the knowledge that will be addressed in the Artifact, as well as its relations, uses, activities. The developer will implement the Artifact as per the specifications. The developer will also contribute with proven efficient patterns, thus increasing the overall knowledge of the PA. The educators will have SL experience; and will be aided by mediators and educators (with knowledge from various fields: social sciences, psychology, computer science etc.). The collaborative/interactive tool to be used will focus on SL.

5.3. Create Object

In order to create the object, stakeholders should define the knowledge area of the Artifact (e.g. literacy), the context in which the knowledge will be worked (e.g. a representation of a daily activity) and the genre the Artifact will represent (e.g. an e-learning book). Brainstorm sessions could be used to derive the overall ideas for the object.

Stakeholders should select the SL signs that will be used to create the interaction elements, knowledge, relations, etc. Such signs should consider the target audience (Deaf children and non-Deaf parents with no proficiency in SL). The process relies on SL signs that have one of the most important and easily recognizable characteristics of SL: its greater iconicity when compared to other natural languages. Each element is composed by its iconic formation as per the hand configuration.

The Artifact will present users with the overall object and its elements. When activated, each element will show an animation of how the signs are in Libras – a ludic manner to demonstrate the iconicity of such element. Later, the student will explore the available elements, and, according to the design of the object, she will be shown animations and videos of the elements and the knowledge they contain (i.e. relations to other elements/concepts).

When creating an object, the following should be considered:

1. The overall area of knowledge of the Artifact (e.g. sciences, health issues etc.) should be selected;
2. The genre to be used (e.g. e-book, instructional LO, storytelling environment, immersive environments, interactive installations, games, distributed interactions over the Internet etc.) should be determined;
3. Within the selected genre, the stakeholders should create a representation, a concrete, actual scenario of interaction that is part of the context of the child (e.g. a scenario of a child’s breakfast situation);
4. Sense Making (an approach used to study the process people use to make sense of their experience) from Dervin [30] and Common Sense (shared knowledge, related to life within a culture) from Anacleto et al. [31] should be used to create tasks that require the comprehension of the chosen topic, and its sub-tasks (i.e. knowledge creation, information seeking, mental and cognitive maps, comparison, synthesis, analyses etc.). The use of said tools will enable the selection of concepts and their respective SL signs that belong to the context. Objects, actions, relations etc. are the tasks that will be implemented as activities performed with the Artifact. Some of the issues to be addressed during this phase, and to be used to represent the knowledge to be ingrained into the object: a) How do people make sense of a set of complex information? b) What are the aspects of representation, evolution and use through time? c) How to effectively make sense in a group? d) How to deal with static and dynamic environments? e) What are the uses of such cognitive theories in other areas of human knowledge?
5. Such process will guide stakeholders on the nature of the object: its components, behavior, features, teaching/learning strategies, testing for knowledge acquisition etc. It incorporates features required by Interactive Learning Environments (ILE) [15].
6. From the selected concepts and SL signs, a sub-set of signs will be prioritized, as per their iconicity.
7. The use of scenarios, from Carroll [32] is a powerful tool: Scenarios provide concrete situations of use to inform design. They also serve as the documentation, as design rationale, requirements, specification and analyses that will be used in the implementation.
8. Iconicity will be used to generate the “Spontaneous Concepts” and help the Deaf children to develop her “Scientific Concepts” [10].
5.4. Create Knowledge base

Given the varied interests of the many stakeholders, and their needs, choice of genre, instructional format, etc., the knowledge of the Artifact should be normalized in order to create the knowledge base to be used in the Artifact. Thus, the SL selected in the previous phase should be organized in a Conceptual Maps (CM) according to Giombini [33].

CM is a representation of concepts (vertices) and their relation (arcs) in a network, which narrates this relation. CM is a powerful tool for meaningful learning as it serves as a template to organize knowledge and to structure it. And its similarity to computational graphs allow for an easy conversion for implementations. Knowledge is presented/created by the exploration and navigation through such network. The algorithm to be used to choose the navigational path is genre-dependent, and thus, is beyond the scope of the II process. Suffice it to say that the path will represent the allowed order in which concepts and relations will be presented to the user.

Stakeholders represent elements (i.e. concrete objects, such as a tree, the sun, the cloud, etc.) and its relations (e.g. the tree has branches – composition, whole/part), a causation (e.g. the sun burns the eye) among other knowledge. This representation is fundamental, and precise criteria must be used in the modeling of the knowledge to be presented (according to the choices made by the stakeholders in previous phases of the process). The knowledge modeled in a CM can be transformed into a graph a $\rightarrow$ b (i.e. IF a THEN b) according to Sales [13] aforementioned, in such a way that the previous knowledge presented is a precedent and is used to create a new knowledge: IF there is sun, and the sun burns the eyes, THEN sunglasses must be used for protection.

5.5. Create Intellectual Interactions

In order to create the intellectual interactions, designers will use the object created by the use of the process presented (including the scenarios, the choice of knowledge area, genre, conceptual maps and other materials that was developed during the creation of the object). The intellectual interactions are the instantiations of an element and its relations, triggered by user exploration. The first instantiation of an element will be of its essence (i.e. if the user touches a tree, then the animation, the sign, and the initial knowledge presented will be that of the tree alone). When instantiated, the Artifact will show an animation of the iconicity of the element (i.e. an animated hand will superpose the element in a direct representation of the element in SL). Then, a video will be played, with additional knowledge (e.g. other concepts, relations and the written Portuguese corresponding to the knowledge presented). The next instantiation is outside the system, which means it can be pre-determined or randomly selected by the user (i.e. it can be initiated by either the mediator, educator, the students, or by a pre-defined order), and it is a choice between the essence of the element and its knowledge (relations). Further activation of any element presents new opportunities for knowledge presentation: it can be a repetition (an important strategy for teaching/learning) or a new concept and its relation. This will guarantee the functional dependencies of the knowledge structure ingrained in the system. Any independent spontaneous knowledge may be instantiated. All dependent knowledge may only be instantiated if their functional dependency is already a part of the instantiated knowledge.

The interactive activation of an element by the user should keep a memory of the knowledge in the domain of the Artifact, so that its dependent relations may be used in later interactions (that is to say, once activated, the element will be marked as visited, and will become a concept from which other concepts could be built). This makes the element a part of the previous knowledge structure of the given session of use of the Artifact.

5.6. Implementation

In order to implement the Artifact, the designer will have to guarantee the functional dependencies mandated by the CM. The main goal of the environment is to present the users with enticing elements that will elicit interaction. Given an activation of an element, the Artifact should then keep track of the presented knowledge as the student explores the element and its relations. The mapping of the CM into a graph is suggested as a simple way to implement such behavior. The choice of which path in the graph (CM) to take next is dictated by the use of the PA. Not all element from the Artifact need to be instantiated, as it is true to the relations. This is a real-world model approach: it may be the case that some elements must be repeatedly presented, in order to fixate a given knowledge; or the user may not come back to an element, thus not exhausting its possibilities in that specific session. Note that the interactions may vary from session to session, from user to user, from moderator to moderator, based on the pedagogical choices, among other variables. In this sense, the intellectual interaction differs from a learning object that must present a sequence of progressive knowledge (although it may also do so).
6. Case study: building a prototype

A prototype Artifact geared towards Deaf children and parents with no proficient knowledge of SL was designed following the proposed PA. It is structured in three basic modules: a knowledge base, the data structure and its related algorithm to control each use session, and the instantiation of the prototype. Figure 3 shows the feedback between these units:

![Image](image.png)

Figure 3. The knowledge base, the system and the Artifact

6.1. The process

The stakeholders (research team, educators, developers) selected iconic SL signs that were used to create the elements, its interaction, knowledge relations, etc. Literacy was the area of knowledge that was in evidence, and the pedagogical approach was that of social-interactionism.

The genre selected was that of a storytelling environment, in a concrete scenario of interaction that is part of the context of the child (i.e. a visit to a park – of which there are several in the city where the Deaf lives). Game is a crucial process in which the child understands ideas, develops skills and participates in social roles [10]. Stories have been used in education to help build a learning context, to increase motivation and involvement: computer interactions that exercise the intellect are experience that have the ability to delight and motivate the user especially if the audience is children: “Story is such a fundamental aspect of relating experiences and making sense of the world around you…” Cillela [34:36].

Iconicity was used to generate the “Spontaneous Concepts” and the “Scientific Concepts”. In other words, the Deaf child will be first introduced to the lexicon by its iconicity and relation to visual elements. Then, through interactions with the parent and the system, more sophisticated concepts will be presented to motivate development. The use of CM allowed the specification of various concepts involving the same iconic SL sign. Thus, even in an environment with few elements, the tool becomes a rich source of material for educators.

For example, for a storytelling environment representing a city park, the TREE is an iconic sign in Libras, and has many concrete and abstract elements associated with it. Figure 4 shows us the methodology of iconic sign formation in SL:

![Image](image.png)

Figure 4. Use of SL iconicity to create lexical elements and concepts

6.2. The implementation of a prototype

The elements in the prototype are comprised of a concrete object (e.g. the sun, a tree, clouds etc.) and its relations (e.g. the sun burns the eyes; sunglasses protect the eyes from sunburn). Figure 5 shows an example of a Conceptual Map (CM) that was generated, representing some knowledge of a city park: sunglasses protect the eyes from the damage caused by the sunrays. It also shows that the trees have branches; if the sun hits the tree, it makes shadow. This representation is fundamental, and precise criteria must be used in the modeling of the knowledge to be presented.

![Image](image.png)

Figure 5. Example of a Conceptual Map of elements found in a city park

Note that the knowledge modeled in Figure 5 can be transformed into the pattern $a \rightarrow b$ (i.e. $IF a THEN b$) according to Sales [13] seen in Figure 6. This transformation will be used to store knowledge in the data structured proposed, to be discussed next.

Giombini [33:1] tells us that “CM are the most effective scientific tool to identify language acquisition processes, its conceptual development, and the instrumental abilities that ensure the comprehension of
written texts for whole life”. Kowata [35] tells us that
use of CM with educational objectives complement the
process of teaching and learning as they provide
incentive for interaction construction of knowledge, to
be used by stakeholders for analysis and patter
definition, organizing knowledge from specialists.

The set of knowledge is a set of spontaneous and
scientific relations. The spontaneous relations are
internal, concrete (e.g. characteristics, attributes,
components etc.). Spontaneous relations are either
independent (i.e. they relate a sub-Element to its
Essence; a new knowledge depends only on the
Essence) or Dependent (e.g. relations of a sub-Element
with another spontaneous relation; a new knowledge
depends on another concept already present on the
cognitive structure. A scientific knowledge is
dependent either on an internal concept or an external
concept.

Intellectual Interactions are the instantiations of an
Element by the user on the Artifact. In other words, the
main goal of the environment is, given an activation of
an Element, to present a relation from such Element to
another. This relation is chosen from the possible
relations, respecting the dependencies. The CM, as
exemplified in Figure 5, will be implemented as a
hyper-graph. According to Guedes [36:2], hyper-
graphs may be used to model problems in which usual
binary relations are not adequate (e.g. relations of
dependency), such as the ones present in the proposed
conceptual meta-environment, in which “[…] the
dependencies are relations between sub-sets of a set of
attributes, that is, they are a pair (X, Y) […]”. That
gives us \(X \rightarrow Y\).

Thus, the hyper-graph was selected, in this
prototype, as the mechanism to manage the concepts,
their relations, and the actual use of the Artifact. The
choice of the hyper-graph was relatively direct, since it
represents the necessary functional dependencies, in a
flexible structure that is easily obtained from the CM.
It also allows for a flexible algorithm to be used to
present the concepts and their relations, keeping
memory of previous concepts. In particular, the hyper-
graph was chosen over a Petri graph because a Petri
structure is dynamic, and has its own algorithm, thus
not allowing for the need flexibility. Also, the type of
knowledge need for Literacy in SL acquisition and
affective tie construction is not necessarily a learning
object (e.g. a subject – addition/subtraction – within a
discipline – Math – where the knowledge is to be
presented in incremental form, a sequence of pre-
determined paths).

Figure 6 presents an example of a mapping of the
knowledge represented in the CM (as seen in Figure 5):
If there is sun, and clouds, they combine to make
shadow; the sun and the tree will also make shadow.

Consider the following scenario: The child and her
parent(s) leave the house, walk a few blocks, and arrive
at the towns central park. All the elements in the story
are those that are commonly found in such traditional
community spaces (Figure 7), and the highlighted
butterfly tree on the right shows the hands forming the
SL Libras sign.

The environment first projects the entire scene,
and then waits for the intellectual interaction to occur.
Whenever an element is activated, then an animation
will show how the sign for the chosen element is
formed. A background video will then appear, with an
utterance that includes the sign for the selected
element, and some information – that will also appear
in written form (e.g. in Portuguese).
6.3. A proposed model of evaluation

Additionally, the PA and its related computational process allowed the stakeholders to build a test environment using the same elements from the prototype. The Model of Evaluation consists of a series of “questions” to which the child and her parent should give “answers”. The Interface presents a video in SL, with options for the answers. In order to test the development of the spontaneous knowledge of a lexical element into a scientific knowledge (how some of the lexical elements are created in SL by its iconicity), Figure 8 shows an example of such instrument: the video shows a signer uttering “BORBOLETA” (BUTTERFLY). The written Portuguese above reads: “What animal is this?” “BUTTERFLY” is considered to be part of the context of the city park. The options will show videos of elements from the Artifact. A child and her parent may select the correct answer based on its iconicity.

Another type of Evaluation would be to evaluate the grasps of relation concepts: the video would ask questions such as: where does the bird live? What does the bird eat? And so on, with the correct options being from elements of the Artifact: the bird lives on a nest in the tree. The bird eats worms.

As for the Evaluation of the proficiency in Written Portuguese, the video would ask the same questions as above, for example, and the choice for answers would be in written Portuguese.

![Figure 8. Screen Shot of a proposed evaluation instrument](image)

During the internal evaluation of this case study, it was verified that this model has the potential to be applied both in the classroom and at home, in a playful way to measure the child’s progress.

7. Considerations and future works

The huge gap between the Deaf child and her non-Deaf parents regarding communication and affective ties due to the lack of SL acquisition is detrimental to the Deaf’s intellectual development. The proposed PA for the design of e-learning tools aims at addressing literacy in SL/Portuguese. Primitives to capture SL iconicity are shown. Then, we provide educators with a framework with which to derive the knowledge base using cognitive theories. This knowledge base, in a CM form, can then be transformed into a hypergraph that will serve as the basis for the implementation. The process structures in a precise way the activities to be used to create the computational tool that implements a PA. Most PA lack such process, and, therefore, our proposal advances the state of the art.

The case study presents a successful use of the proposed PA and its process to build a prototype. Among the findings during the case study that are noteworthy are: a) the use of CM was very effective to overcome communications barriers among stakeholders; b) The use of cognitive theories, such as SM and CS allowed for the construction of a rich knowledge base; c) the overall process allowed for the creation of the accompanying Model of Evaluation, to measure learning progress; d) the use of iconicity allowed for better understanding of the prototype, and memorization of the concept.

As was observed during the case study, the concepts may be re-used in other contexts, hence the need to create a Patterns system. Patterns are a separate system that refers to and will store the SL sign for future use. It should contain its iconicity, relations, areas of knowledge where it can be used, best practices that have been shown effective, context of use, codes for the implementation, images, videos etc. Patterns are to be deposited in a repository for knowledge management (creation, updates, re-use) by the stakeholders. Members of the Deaf community will contribute in the process, along with other stakeholders, in the creation of the patterns, using the logistics of Less Commonly Taught Languages (LCTL) from CARLA [37] and other techniques.

The creation of the Patterns is now implemented in a Collaborative Web Portal for internal use. At present, to apply the process requires extensive participation of members of the Deaf community, a feat which requires further research: usability aspects, for instance: how to deploy such web portal for the geared towards their specificities, where stakeholders can use, create, share. This is a task that will be addressed in future works. Additionally, once there is a substantial repository of patterns available, the creation of the Artifacts can be, in the long run, automated: designers could navigate the patterns, and aggregate them into the tool. Our future work will contemplate such issues. The
continuation of the evaluation will be performed with educators, designers and the target audience.

8. References

[34] S. Cillela, “Did you ever know that you’re my hero? The power of storytelling”, Interactions, V.XVIII.1, p. 620066, 2011.