A Learning Disabilities Model and Solutions Collection for an Adaptive Dialogue System for teaching

Mohammed Taouil, Ahlame BEGDOURI, Aicha Majda

Abstract*— In the last decade, a large rise in the number of learners with learning difficulties has been observed. This problem is serious since it has a direct impact on the education of young children and their integration into society in the future. The adoption of tools supported by ICTs is a good solution to help them to succeed in their learning. These solutions become more motivating when it comes to presenting them as a serious game or even as an intelligent dialogue system. The main goal of our research is the design of an adaptive intelligent dialogue system, as a learning support to an apprentice with learning disabilities. Several studies have been conducted in this direction, but each of them dealt with a specific learning difficulty and a unified vision of the learning disabilities remains an increased need. In this paper, we aim to propose a representative data model of Learning disabilities as well as a collection of ICT supported solutions organized according to this classification of learning disabilities. Both, the data model and the solutions, will be exploited later to design an adaptive dialogue system for children with learning difficulties.

***Index Terms*— Adaptive system, context-aware, intelligent dialogue system, learning disabilities, Serious Games.**

I. INTRODUCTION

Currently, millions of children suffer from serious learning problems and their related issues. In order for the parents, teachers and assistants to be able to help them, they need to learn about learning disabilities and develop a better understanding of the potential reading, writing, math and attention difficulties. Moreover, they need to learn specific strategies and techniques for responding to these difficulties, and consult different learning disability experts.

Learning disabilities (LDs) concern a wide range of disorders, ranging from speech and language disorders to motor skill disorders [1][2]. The most notable disorders are those directly related to scholar achievement, mainly specific disorders of reading, calculation and writing. One of the solutions to these problems is the use of a specific form of educational learning systems: serious games. After all, game-based learning systems can help the learner focus on the learning material while providing him a fun experience. Moreover, serious games are one of the best ways to maintain the attention and motivation of the learner by making interaction with the game environment. Compared to the traditional learning systems, game-based learning has the ability to provide more attraction to the learners while stimulating their psychomotor by using the computer along with developing their thinking skills while having fun playing the game. However, most games for primary school pupils are often intended to "normal" learners and do not take into account some particularities of learners with specific needs such as Learning disabilities.

In order to offer a better learning experience, the game may use an adaptive system, which is a collection of coordinated units, forming a unified assembly, capable of responding to environmental changes or external interactions. Some of artificial adaptive systems include robots and tutor systems.

Depending on the situation, the game may need to provide a more organic feel to the experience and involve the learner in an interactive dialogue through an intelligent dialogue system. Indeed, an intelligent dialogue system or a "chatterbot" is a program that attempts to converse with a person, for a few minutes or more, by giving him the impression of conversing with a human. In other words, the purpose is to mimic the behavior of a human tutor as an instructional expert and/or an expert in the learning subject while maintaining the illusion of interaction with a human being.

The main goal of our research is the design of an adaptive intelligent dialogue system, as a learning support to an apprentice with learning disabilities. In order to identify relevant adaptation rules, the first step of our work is, on one hand, the design of a generic Learning Disabilities model allowing to describe precisely any kind of LD that could be encountered within young learners, and on the other hand, the gathering of possible ICT supported measures helping the education of these learners.

In this paper, we start by presenting in section II, the concept of learning disabilities and some common examples of LDs that could be encountered inside a classroom, as well as the concept of intelligent dialogue systems. In section III, we present some previous research works related to LDs and intelligent dialogue systems. In section IV, we introduce our proposed LDs model followed by a categorization of their related solutions. Finally, we end the paper by a conclusion and perspectives.

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II. BACKGROUND

A. Learning disabilities

In 1877 the German neurologist Adolf Kussmaul first used the vocabulary of "word blindness" to describe the special case of complete written words blindness even though the sight, intellect and speech are normal [1]. This was the birth of the idea of specific reading disability.

In the 1920s, researchers in the United States started to get interested in the work of the Europeans studying relationships between children and adults with learning difficulties and brain-behavior. These researchers focused on language and reading disabilities, perceptual capacities, and attention problems.

The "learning disabilities" concept was conceived from observing children with hyperactivity and impulsivity, for whom there was no clear cause of these conditions [1]. Most historical resources give the credit of defining the term (LD) to Samuel Kirk in 1962.

The term learning disabilities began its introduction as a formal category, by the education and medical professionals between 1960 and 1975 in the United States [1]. Between 1952 and 1994, the learning disabilities appear in the first three versions of the "Diagnostic and Statistical Manual of Mental Disorders" (DSM). The DSM is a manual published by the American Psychiatric Association (APA), which offers a common language and standard criteria for the classification of mental disorders. In these versions of the DSM, the learning disabilities were under the specific developmental disorders.

However, in the fourth iteration of the DSM (DSM-IV) of 1994, the terminology "learning disorder" was used including reading disorder, mathematics disorder, disorder of written expression and learning disorder of nonspecific origin. This classification was used until 2013 with the DSM-V, in which a distinction between specific difficulties and nonspecific difficulties was made.

According to Kirk [3], a learning disability means problems with the development in one or more of the processes of speech, reading, writing, language or arithmetic due to a possible cerebral dysfunction. However, the disabilities are not a result of mental retardation.

In recent definitions [4], "Learning disabilities" is a term describing a diverse group of disorders defined by substantial challenges in obtaining and utilizing speaking, reading, listening, writing, reasoning and/or mathematical capacities.

In general, most of the definitions are based on that "Learning disabilities" means a dysfunction in one or more of the basic neurological processes involved in understanding or using language, which may manifest itself in an imperfect ability to listen, speak, read, write, spell, or perform mathematical calculations. The term includes cases such as dyslexia, and developmental aphasia. The term does not include children who have learning disabilities that are primarily the result of emotional disturbance, mental retardation or of environmental, cultural, or economic disadvantage [2].

We adopt the definition of "Learning Disabilities" as a general term for a diverse group of processing dysfunctions, which can impede learning, in a typical manner, of basic skills such as reading, writing and mathematics. Additionally, they can cause a weakness in higher-level mental skills like abstract reasoning, long or short-term memory, organization, attention and time planning.

In our work, we consider learning disabilities as disorders that inhibits the abilities of certain individuals to learn in the same manner as others. We lean towards the belief that "Learning Disabilities" are not related to the intelligence of the person. They are usually physiological, meaning that the brain of an apprentice with LD is different from other people's brains, however, neither better or worse.

Due to the numerous mental processes that affect learning, learning disabilities have a wide range of variety. In the next paragraph, we present some of the most common learning disabilities that could be observed in a classroom.

B. Common learning disabilities in a classroom

1) Language difficulties

The language difficulties concern the learners who cannot speak or speak badly. They are intelligent but seem to misunderstand, have trouble reading and/or writing (dyslexia, dysorthographia, etc.).

2) Mathematics difficulties

"Developmental dyscalculia" is a disorder that occurs in childhood during the period of learning arithmetic. It occurs in some children who, although having a normal intelligence, cannot solve simple equations. These children are unable to assess small quantities by the naked eye as two or three objects placed in front of them. They are also facing a greatest difficulty understanding that one number may be larger than another.

3) ADHD (Attention Deficit Hyperactivity Disorder)

Attention Deficit Hyperactivity Disorder (ADHD) is a neuro-developmental disorder characterized by concentration difficulties that may, or may not, be associated with hyperactivity or impulsivity. As a result, these kids spend most of their time in their own world and miss their classroom's lessons. Therefore, ADHD can be the cause and a symptom of learning problems.

4) Memory related difficulties

Three types of memory are important for learning, namely, working memory, short-term memory and long-term memory. They are used in the processing of both verbal and non-verbal information. If there are deficits in any or all of these types of memory, the ability to store and retrieve information required to carry out tasks can be impaired.

5) Body control

Dyspraxia is a specific disorder of learning characterized by a difficulty in organizing the gesture. It is a dysfunction

of the coordination and planning of these gestures, like the difficulty to program and to automate the coordination of the voluntary gestures. For example the force and direction of movement of writing and reading.

Dysgraphia is a difficulty in performing the particular gestures of writing. Dysgraphia is a transcriptional handicap, which means that it is a graphic disorder associated with disabling graphic gestures, orthographic coding (spelling), and finger movement during writing.;

6) Difficulties related to personality traits

The lack of self-confidence is the most common difficulty related to the personality traits that could be observed in a learner. Indeed, self-confidence allows a person to have positive and realistic view of himself, and of the situation in which he is involved. Typically, a lack of self-confidence is characterized by a lack of trust in oneself and abilities, and a paralyzing fear and anxiety when faced with tasks a learner wants or needs to do, which consequently, causes behaviors that prevent a normal learning process.

The lack of interest in others is another difficulty related to personality traits, characterized by a tendency towards a solitary lifestyle, secretiveness, and irrational fears of humiliating oneself in social situations. Consequences can be seen in non-involvement in group work, lack of communication, etc.

These learning disabilities can manifest with varying degrees of severity while some learners may struggle with more than one disability at the same time.

Learners with LDs require different learning methods, these methods can be difficult to implement in a classroom under normal circumstances since they need more attention from the teacher. An intelligent dialogue system is a possible solution to this problem, since the system can provide specific help for learners with minimum intervention from the teacher. in the next paragraph, we give an overview of the intelligent dialogue systems.

C. Intelligent dialogue systems

The concept of human-machine interaction using natural language is not new. It started to emerge in the 1950s with the Turing test. Nevertheless, this idea is still relevant today. Indeed, there are annual competitions in this domain such as the Chatterbox Challenge and the Loebner contest, aimed at passing a test and thus imitating human verbal interaction [5].

Intelligent dialogue systems or conversational agents are generally divided into two main classes:

- Task-oriented conversational agents, which conduct conversation in order to achieve a certain objective such as hotel reservation, teaching a subject, etc;
- Non-task oriented conversational agents intended to converse with the user on any subject with an often friendly relationship, such as ALICE (Artificial Linguistic Internet Computer Entity). A program that allows a conversation with a human by applying heuristic rules of keyword recognition to the input of the human [6].

Task-oriented conversational agents are themselves usually classified into two categories:

- Service-oriented conversational agents. For example, guiding customers through the process of booking a plane ticket
- Educational conversational agents with the objective to help the user to learn.

For this category, the most common elements of the various developed architectures could be summarized in the following components:

- A knowledge base inherent to the domain, subject of the application. The system has its local knowledge base and, in some cases, it can have the ability to get more data from the Internet;
- A response manager. This manager is responsible of managing the conversation (give a question, give an answer etc.) and structuring the system's answer in a comprehensive manner;
- Storage solution for the conducted conversations, to give the system the ability to perform some actions like learning evaluation, generating statistics and to allow the system to make its inference [7].

The intelligence of an intelligent dialogue system is implemented using: i) basic rules covering, as broadly as possible, the field of conversation and the structure of the conversation itself; and ii) rules of deduction, which allow the system to create its own complementary rules.

"Fig 1" is an example of a tutor agent architecture [8]. The user gives a statement in a natural language, which is translated by the response manager to the Artificial Intelligence Markup Language (AIML: an XML-derived language used to manage the knowledge of bots). The manager divides then the statement into topic related part and communication pattern related part and generate a template for the response. Afterwards, the search engine (or inference engine) uses both, the manager's output and the knowledge base to generate an answer which is reformulated, by the manager, and presented to the user in natural language.

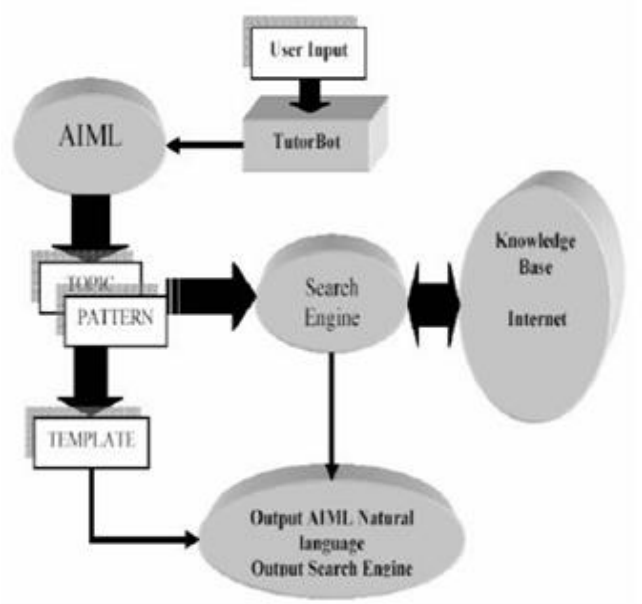

Fig 1. Example of a Conversational Agents Architecture [8]

As for non-task oriented conversational agents, they are known as “chatbots”. They are systems designed for extended conversations, configured to mimic the unstructured conversation or "chats" characteristic of human-human interaction, rather than focusing on a particular task. They thus, do not require a domain specific corpus. These systems often have entertainment value. However, “chatbots” are also used for practical purposes, such as Google assistant.

In general, discussion robots are implemented either by generative methods or by methods of recovery:

- Generative models are usually based on machine translation techniques, but instead of translating from one language to another. They "translate" from an input to an output. These models are able to generate more appropriate responses than that could have appeared in the learning corpus. The basis of the neuronal generating models are sequence-to-sequence models, more precisely, a sequence-to-sequence model is an encoder-decoder structure. The encoder reads word by word (the Xi) and represents it as a context vector (Context in Fig.1) through a recurrent neural network (RNN), and then the decoder estimates the probability of generating a response with same vector as input.

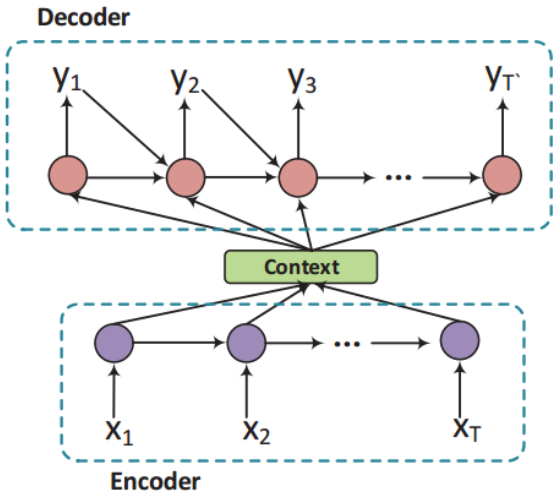

Fig 2. An Illustration of the Encoder-Decoder Model [9]

- Recovery-based methods do not generate any new text; they simply choose a response from a fix set of candidate responses. The core idea of recovery-based methods is that the message matches the response. The corresponding algorithms must overcome the semantic gaps between messages and responses. These models use a predefined response repository and a method for choosing an appropriate response based on input and context, and could be as simple as a rule-based expression correspondence, or as complex as a set of Machine Learning classifiers.

III. RESEARCH WORKS RELATED TO LDs AND LEARNING

In the field of education, there is a wide range of educational intervention programs that have been developed and tested in order to provide quality education to young children with learning disabilities. As an example, the UCLA YAP model focuses on learners with autism [10]. It is a teaching environment, based on the fact that children with autism struggle to understand and communicate with others, then respond to these frustrations with other difficult behaviors. Therefore, this teaching environment was designed to maximize a child's success and minimize failure. The desired behavior, such as use of language, is reinforced and accompanied by praise, while negative behaviour (for example aggression towards others) is not reinforced. In this environment, the therapists may use a variety of specific teaching technics including discrete trial training, incidental teaching and a wide range of other methods, such as sign language.

Another example "The Joy of Reading" is an intervention program aiming to increase reading motivation for kids with learning disabilities [11]. It includes intensive exposure to daily structured reading activities, encouraging pupils' involvement in various reading and writing activities building

up a sense of personal competence and self-confidence. In order for the program to achieve its goal, it makes use of numerous activities designed to improve memory, organization, systematic work, language and attention.

These examples requires a specific environment, and trained personnel in psychology to be effective. On another hand, the use of Information and Telecommunication Technologies (ICT) gives the ability of creating new tools to improve and facilitate the conduct of these intervention programs. In the next few paragraphs, we highlight some examples of the realized works in special education fields and some examples of the use of dialogue systems for educational purposes.

The first example is “Success Maker” (that we note “a” for further reference later on this paragraph) [12]. It is an integrated learning system designed to help kids with learning difficulties, learn. It presents an individualized experience in learning basic mathematics, based on the cycle: evaluate, attribute, adapt and alert.

The second one is a multimedia learning resource for children with LD (that we note “b”), developed in a study conducted in Malaysia [13]. This multimedia resource focuses on the behavioral aspect of the pupils. Its objective is to change the behavior of the learners by involving them in a story of the daily conducts of an abstract learner in school, using simple text, oral narration and sliding images.

Fig.3 shows four simple screenshots of the example “b”.

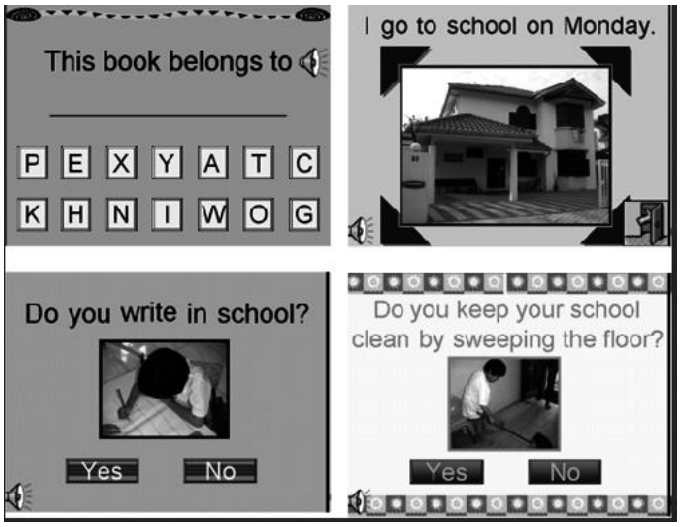

Fig3: Sample slides from the Social Story [13]

The third example "Playtime Learning" (that we note “c”) is a multimedia tutorial, which can be used to educate children with learning disabilities [14]. It focuses on materials that can stimulate children's thinking skills, by providing two types of actions: fun activities and play games.

Fig.4 is the main screen of “Playtime Learning”.

Fig4: playtime Learning interface [14]

The fourth example “Block Challenge” (that we note “d”) is a collaborative virtual reality environment [15]. It is an environment where a child must communicate and collaborate verbally with another child and understand his perspective in order to succeed the game.

Another example is the AutoTutor project (that we note “e”) intended for higher education learners [16]. It is a learning environment that tutors students by holding a conversation with them in natural language. It provides tutorial dialogues on different subjects such as physics and computer literacy. The tutoring methods used by this system are based on analysis of tutoring sessions by human tutors, and help learners to actively build knowledge.

Fig.5 shows an example screen of “AutoTutor”.

Fig5. A computer screen of AutoTutor for the subject matter of conceptual physics [16].

The sixth example, K-Inca (that we note “f”) [17]. It is an artificial conversation agent designed to help people adopt knowledge management practices. This agent analyses the actions of the user to build a behavioral profile, then the agent use this profile to provide customized guidance to support the transformation of the user’s behaviors.

Fig.6 shows a screenshots of “k-InCa” system.

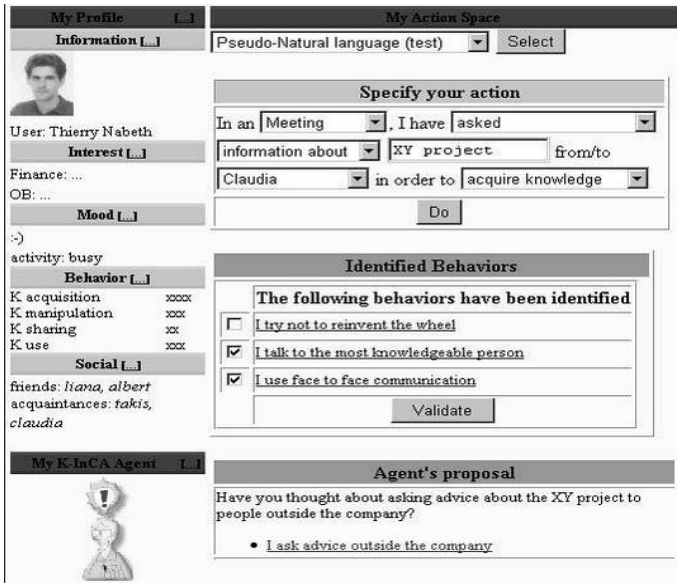

Fig6. K-InCA system screenshot [17]

The seventh example, Ms Lindquist (that we note "g") [18]. Another tutorial system uses dialogues. This system uses action learning (taking an action and reflecting upon the results), rather than offering explicit instruction, to offers tutoring to high school students in algebra.

The last example is the conversational intelligent tutoring systems (CITS) (that we note "h") [19]. This system, like every dialogue system, uses natural language to communicate with learners to provide an SQL tutorial. In addition, it take into consideration the student's learning style and adapts to it based on the index of learning styles (ILS) model.

As a synthesis, and in order not to get far from our topic of intelligent dialogue systems support for learners with disabilities. We compared in TABLE I all of these systems according to some indicators: i) the considered LD, ii) nature of the system: Intelligent System (IS) or Dialogue System (DS), and iii) type of the system (serious game, multimedia resources, tutorial system, learning environment, etc.)

TABLE I
COMPARATIVE TABLE OF RELATED WORKS SOLUTIONS

System	LD	AI/ DS	System type
(a)	Math disabilities	AI	adaptive learning system
(b)	Behavioral disabilities	No	multimedia learning resource
(c)	Math and reading disabilities	No	Serious games
(d)	Behavioral disabilities	IDS	Serious games
(b)	Behavioral disabilities	No	adaptive learning system
(e)	No	IDS	adaptive learning environment
(f)	No	IDS	artificial conversation agent
(g)	No	IDS	tutorial system
(h)	No	IDS	artificial conversation agent

As a synthesis, we can say that even if these systems perform well, each one of them has its own shortcomings. The "success maker" system (a) is an adaptive system. However, this adaptation is only based on learners' mistakes, and does not take into account the communication aspect. The second work (b) does not include a concrete dialogue system but is oriented towards changing the learner behavior in school environment. The third system (c) is an example of using games in education. However, it is not an adaptive nor an intelligent system. For the fourth example (d), it focuses more on the development of communication abilities of the learners. Unfortunately, this configuration, as it is, cannot be used in an ordinary class of formal education. The last four systems (e, f, g, h), are great examples of intelligent dialogue systems in education, however, they are intended for a higher learning levels and are not directed toward helping learners with learning disabilities.

IV. OUR LEAENING DISABILITIES MODEL

A. *General architecture of our dialogue system*

In this paragraph, we present our proposed general architecture for an intelligent dialogue system support of disabled learners. We remind that in the field of computer systems engineering, functional architecture is a logical representation of hierarchical relationship between the various function-based components of the system and the related data flows.

For a better understanding of a disabled learner, and in order to give him the most appropriate answer, the system should take into account the learner limited ability to provide a correct input during the dialogue (spelling difficulties, writing style, etc.). In addition, the system must assist him to correctly express himself, which could be achieved using a limited but evolving knowledge base.

The dialogue system must also be able to adapt automatically to all of the other parameters related to the educational context such as the learner's needs in relation to the subject taught, his learning style, the proposed activities, duration, etc.)

In "Fig. 7", we present the general architecture of our proposed system.

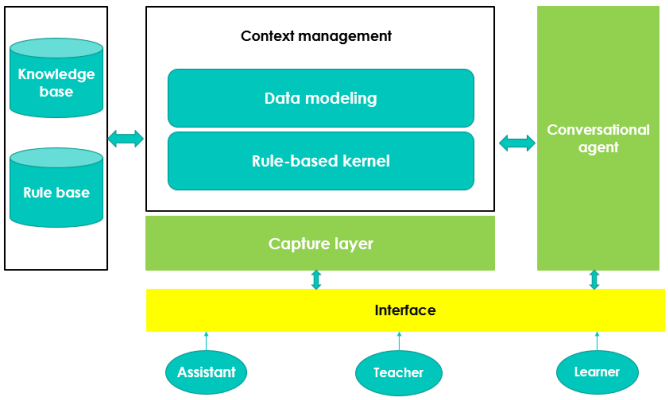

Fig 7. General architecture of our adaptive system

The layers of this architecture are explained as follows:

• Interface: This layer allows the users (Learner, teacher, parent etc.) to interact with the system according to their needs. Different screens, according to the user type, manage these interactions.

• Conversational agent: Is the system part in charge of the communication with the learner. It represents a common conversational agent implementing, as described in "Parag.II.C.", the basic functionalities of search engine and response manager.

• Capture layer: responsible of capturing explicit information characterizing the learning situation. This information is necessary for the context management component to be able to implement its adaptation strategies. The task of capturing the context parameters could involve several kinds of sensors such as cameras, motion detectors, etc.

• Context management: The objective of the context management subsystem is to identify the most appropriate action to be done in response to a specific learning context. To do this, it is divided into two sub-components dealing with data modeling and with adaptation rules. These latters are either static or dynamic rules deduced by the system itself.

In order to achieve a good adaptation system it is necessary to have an implemented model for each varying aspect of its work environment. Therefore, we propose the following four dimensions for our data modeling "Fig. 8":

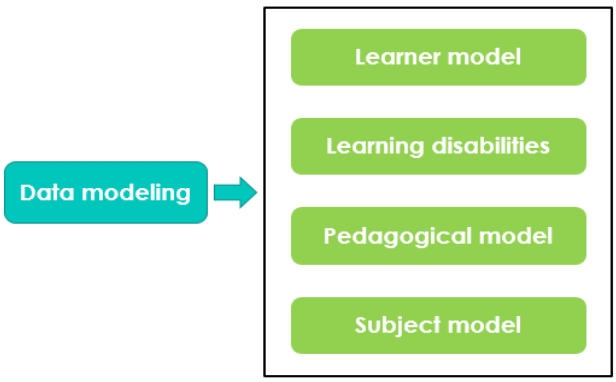

Fig 8. Dimensions of our data modeling

- Learning Disabilities model: it represents the characteristics of the supported disabilities allowing the system to respond and adapt to each difficulty in a proprietary manner. This model, being the main contribution of this paper, will be presented in details in the following paragraphs.
- Learner model: This model is a representation of the different information concerning the learner as a system user and as a learner (name, age, level of study, knowledge level in a given field, learning style, etc.).
- Subject model: The model of the subject, also called expert model, represents the expertise of the teacher in the field that the system is going to tutor. In other words, it represents the knowledge that must be taught to the learner and what skills he should acquire.
- Pedagogical model: contains general methods for teaching in a wide range of situations. Moreover, since we have chosen to create a serious game, this model will contain, between others, the game's educational scenarios.

B. Learning disabilites' classification criteria

After conducting a detailed analysis of the LDs characteristics according to both, health and educational points of view, we identified the most important criteria for characterizing the LDs as follows:

- Origin of the disability (Behavioral or Neurological);
- Type of the disability (visual, auditory or memory related);
- The impaired learning function (reading, writing, math);
- Information processing stage in the learning process (input, integration, storage, output).

a) Classification by the disability origin

The origin of Learning Disabilities observed in a learner could be either of behavioral or neurological origin. Indeed, the neurological based processing problems inherent to an individual may cause him a LD. These problems can alter different learning skills such as reading, writing, math, abstract reasoning, time planning, organization and memory. The neurological disabilities can thus manifest in a big number of forms. They are the object of the classification presented in the following paragraphs.

As for the behavior, problems in self-regulatory behaviors, social perception, and social interaction (such as loss of attention, absence of communication etc.) may cause learning disabilities.

We divide behavioral disabilities into two classes: i) the difficulties related to the learner's personal behavior which generally appear as restricted, stereotyped and repetitive activities and behavior, and ii) the difficulties related to his behavior within the society; which appear as qualitative disorders of verbal and nonverbal communication as well as qualitative alterations of social interactions. They mainly manifest as interactions difficulties or communication difficulties.

The personal behavior disabilities within a learner could manifest in two aspects:

• Inattention: where the learner is easily distracted, does not finish tasks, does not pay attention, makes careless mistakes, forgets about daily activities, has problems organizing daily tasks or tends to daydream.

• Hyperactivity: where the learner does not like activities that require sitting still and often squirms, fidgets, or bounces when sitting.

The interaction difficulties are due to:

- The impulsive character of the learner who has the tendency to act without forethought, displaying behavior with little or no thinking, reflection or consideration.
- or to the lack of interest in others and things, where the learner has the tendency towards a solitary lifestyle, secretiveness and irrational fears of humiliating oneself in social situations. On the other hand, this lack of interest in things affects his motivation, efforts, attention and the time he is willing to give to perform a certain task.

With regard to the communication difficulties, they are mainly due to:

- The lack of attention to the others: where the learner has the tendency to not listening and following directions and to be easily distracted in a conversation.
- or to the lack of confidence: where the leaner feels a lack of trust in himself and his abilities as well as a paralyzing fear and anxiety when faced with tasks he wants or needs to do.

We summarize in Fig.9 our proposed classification of LDs according to the behavioral disability origin.

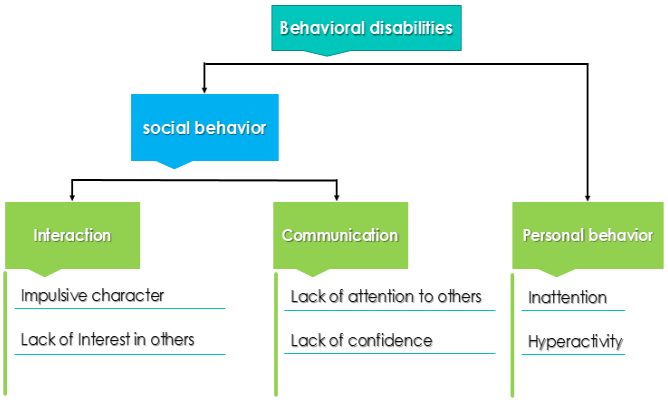

Fig 9. Subclasses of behavioral disabilities

b) Classification by disability type:

From a purely medical point of view, the disability is whether of a visual, auditory or memory origin.

- Visual: how well a learner can use visual information. When seeing something, does s/he understand it quickly and easily? Can they “picture" things in their minds? Can they recall information that they see?
- Auditory: include how sufficiently a learner can understand auditory information. The difficulties affect how the brain grasp and process the ear’s input.
- Memory: how well can the apprentice remember the information in order to be easily accessed in the future?

c) Classification by the impaired learning function:

According to the “World Health Organization” (WHO) there is three general learning functions that LDs are likely to manifest in, which are reading, writing and mathematics.

- Reading disabilities: generally manifest as difficulties of recognizing letters and words, inability of breaking up words into sounds, understanding words and poorer fluency.
- Written expression difficulties include struggling with spelling, handwriting, organizing ideas and composing words.
- Mathematics disabilities: include difficulties to learn math concepts (quantity, place value, and time), organize numbers/math problems and remember math facts.

d) Classification by information processing stage in learning

In the psychology of learning, the cognitive model is the most adopted one. It allows explaining the mental process that leads to the learning in terms of four steps. Considering that we need to perform a classification of LD for learning purposes, we adopted these steps as one of our main LD classification criteria:

- The input level: presenting the ability of taking in the information and decoding it. The difficulties of this level include those related to visual perception and leading to recognition problems, difficulties with tactile information and challenges in auditory perception etc.
- The integration level: meaning the capacity to integrate that information with previous knowledge or experience. This level’s difficulties can manifest as problems in sequenced storytelling, difficulties with comprehension etc.
- The storage level: in other words, the ability of storing the information to be easily accessed for further understanding. For this level, the difficulties are related to memory (short term or long term). For example, problems with visual memory affecting spelling.
- The output level: the skill to encode a coherent and relevant response. At this level, difficulties include challenges in the formulation of expressions with gestures, words, drawing or writing.

C. Learning Disabilities general classification

In this section, we summarize the previous classifications in one coherent data model “fig 10”.

First, we divide the learning disabilities as having behavioral or neurological origin. Behavioral disabilities concern the learner’s personal or social behavior. This latter may affect both, social interaction or social communication. For neurological disabilities, we tried to categorize them according to the most relevant criteria that were adopted by the stakeholders from the health and educational domains, which are: i) information processing stage (input, integration, storage and output), ii) the impaired learning function (reading, writing, and math); and iii) the disability type (visual, auditory and memory).

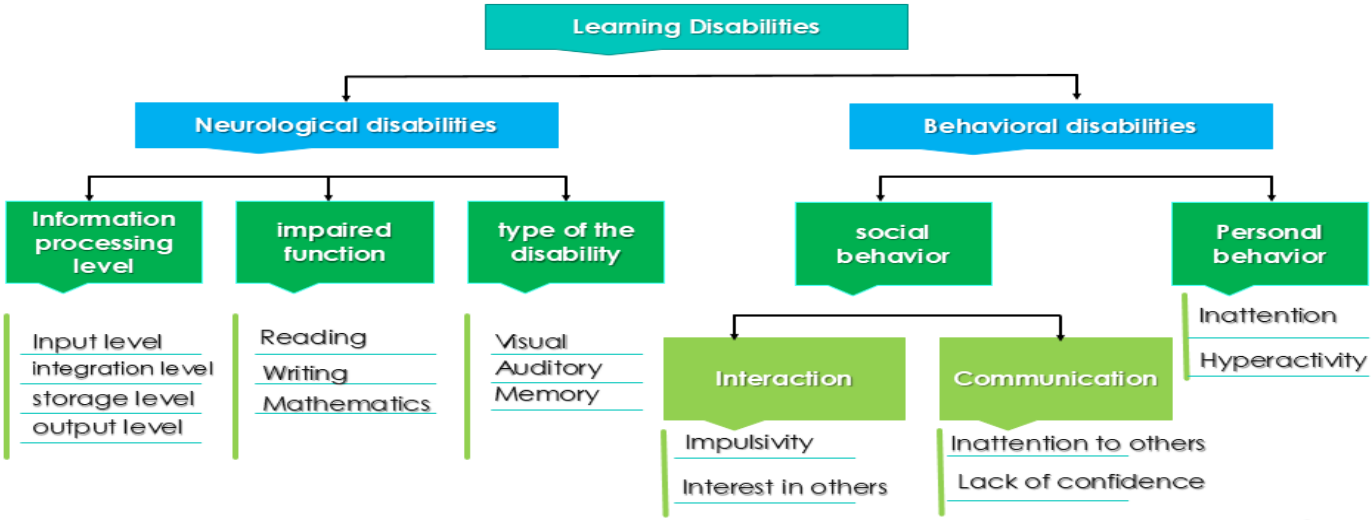

Fig 10. Our Learning disabilities model

V. LEARNING DISABILITIES HIERARCHY AND SOLUTIONS

A. *Learning disabilities' solutions hierarchy*

By understanding the nature of the neurological disabilities, we determined that the classification by the impaired function and by type of disability, are often subclasses of the classification by information processing stage. "fig 11" below is a visual presentation of this hierarchy where "R" stands for "Reading", "W" for "Writing", "Math" for "Mathematics", "Vis" for "Visual", "Aud" for "Auditory" and "Mem" stands for "Memory".

It is to be noted that the visual, auditory and memory in the context of learning disabilities, refer to deficits in the brain areas responsible for these functions, and not deficits in the organs (eyes, ears) themselves.

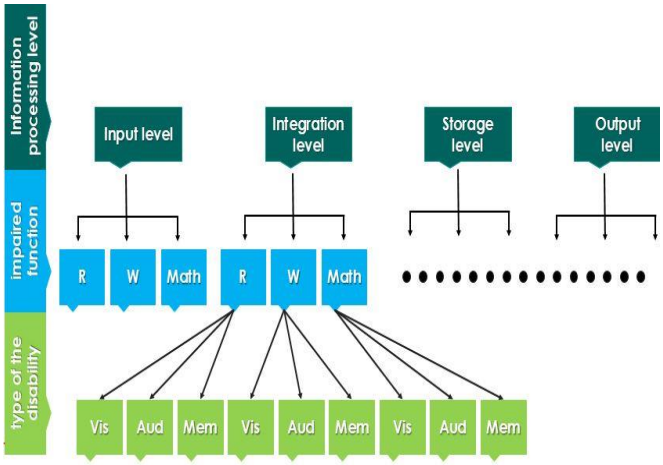

Figure 11. Learning disabilities hierarchy

B. *Categorization of LDs' solutions*

With the aim to implement an adaptive educational system, we need to define, in addition to the LDs model, a set of measures and solutions that an ICT supported system should provide to a disabled learner.

Therefore, based on the LDs model presented above "fig 10", we propose in "fig 12" a categorization of the potential solutions according to the 3 dimensions adopted in classifying the LDs.

Indeed, following the WHO (World Health Organization) which defines the three general learning functions that LDs are likely to manifest in as reading, writing and mathematics, we chose to center the solutions around this impaired functions as our first dimension. The second dimension concerns the type of the disability (visual, auditory and memory). Finally, our third dimension concerns the behavioral branch of the LDs model. Since we are here talking about solutions, we chose to gather all the behavioral aspects that may cause LDs (personal and social learner behavior) under the two main concepts of lack of motivation and of self-confidence. Indeed, we advocate that the solutions dealing with the learner's motivation and self-confidence will surely address one or more of his behavioral difficulties.

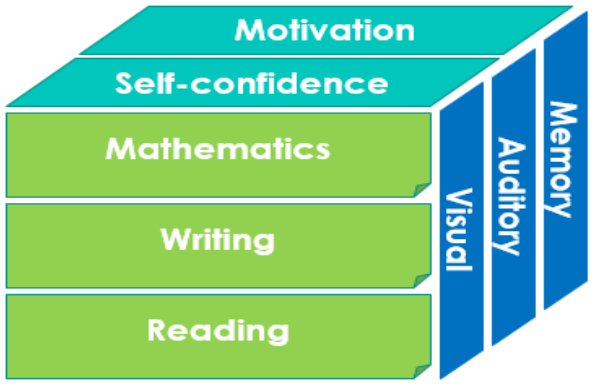

Figure 12. Dimensions of LDs' solutions categorization

C. Collection of LDs' potential solutions

In this paragraph, we present a collection of the potential solutions to be taken into account in developing an adaptive system support of disabled learners. We present them according to the above mentioned dimensions of Fig.12.

- Solutions for reading LDs
  - Use simple, concrete, repetitive language with visual information.
  - In addition to visual information use simple, clear and repetitive audio.
  - Avoid complex language as irony, metaphors and imagery, depending on the learner's level.
  - Use adequate fonts, lining and colors. Well ventilate paragraphs and make short sentences.
  - Use tables, charts, illustrations, films.
  - Break down written instructions and simplify them.
  - Simplify instructions with short sentences, simple words and avoid multiple meaning words.

- Solutions for writing LDs
  - Provide images and visual information to enable the learner to express.
  - Not penalize spelling elsewhere than in dictations.
  - Accept voice commands.
  - Rather use yes/no questions (so yes/no answers).
  - Accept poorly written or misspelled answers if the background is correct.
  - Evaluate by multiple choices, texts with holes, diagrams or tables to complete, sentences to link or to validate/invalidate rather than asking for writing an answer.
  - Evaluate orally or by audio recording on MP3 or Dictaphone.
  - Use of spell check for homework or in class.
  - Give more time for evaluations or lighten the exercises.
  - Check understanding and copying of letters (d/b, p/q, etc.), numbers (6/9, 14/41, 95) and signs (<,>).

- Solutions for mathematics LDs
  - In the early stages of teaching new mathematical skills, ensure that the mathematical problems are free of large numbers and unnecessary calculations.
  - Break Tasks Down into Subsets.
  - Provide prompts of strategies to use.
  - Teach more than one way to solve mathematical operations.
  - Use concrete materials and start from practical activities.
  - Talk or write out a problem.
  - Draw the Problem: Encourage learners to visualize mathematical problems. Allow them to draw a picture to help them understand the problem and ensure they take time to look at any visual information such as charts and graphs.
  - If the learner does not have co-existing reading difficulties, encourage him/her to read problems aloud.
  - Valuing the reasoning in the notation more than the result that is sensitive to inversions of numbers and signs.

- Solutions for visual LDs
  - Avoid shiny white paper/screen.
  - Give instructions in written and oral form. Read problems aloud.
  - Suggest that student compare notes with other students.
  - Experiment with different kinds of lighting and colored acetate overlays.
  - Suggest use of tracking tools when reading.
  - Avoid using italic fonts
  - Use uncluttered fonts like Arial, Comic Sans, Century Gothic, Verdana, and Trebuchet.
  - Use large print documents.

- Solutions for auditory LDs
  - Use images, symbols or written words (depending on the child's understanding) to accompany the spoken words.
  - Slow down the verbal flow and use redundancy.
  - Give only one piece of information at a time.
  - Make short sentences.
  - Use tables, charts, illustrations, sub-titled films.
  - Break down spoken instructions and simplify their wording.

- Solutions for memory LDs
  - Highlight information to remember with color, frames, etc.
  - Provide a list of frequently used words to help the learner remember them.
  - Provide short summaries of the lesson with the main elements to remember.
  - Provide reminder hints.
  - Use of flash-cards scenarios for memorization activities.
  - Deepen the learning by heart of procedures.
  - Train the learner identifying the procedures to be applied in a specific type of situation.
  - Make short and simple instructions.
  - Establish routines in the classroom (a classroom routine is simply a well-rehearsed response to a teacher's directive). Since routines are repetitive by nature, they are easier to remember by learners.
  - Make use of mnemonics and visual prompting cards to assist students in memorizing rules, formulae and tables.

- Solutions for increasing learners' motivation
  - Divide complex instructions into sub steps
  - Use visual aids and videos that focus the attention more than words.

- Vary the intonation during the lesson to attract attention.
- Make many small breaks.
- Limit visual distractions in the classroom.
- Lighten the size and duration of exercises and assessments.
- Start from the concerned group interests according to their age.
- Use games, animations, 3D avatars.
- Virtual reality for simulation.
- Use a rewarding system.

- Solutions for increasing learners' self-confidence
  - Always, accentuate the positive aspects of the answers.
  - See the learning in errors or mistakes. Turn mistakes inside out and focus on what was or will be learned from the mistake.
  - Avoid criticism. Those suffering with low self-esteem struggle the most when given criticism. Be sensitive to this and always, remember that self-esteem is about how much children feel valued, appreciated, accepted, loved and having a good sense of self-worth.
  - Expectations must always be realistic.
  - Provide differentiated instructions to ensure that the types of tasks/expectations match the child's strengths and ability levels.

VI. CONCLUSION

In this paper, we presented a deep state of the art on the learning difficulties that can be observed with a young learner. We proposed a generic learning disabilities data model as well as a general categorization of their potential solutions. This is nothing more than the first step towards our objective of implementing an intelligent dialog system for different learner profiles (with and without learning difficulties). The next step of our work is the exploitation of the learning disabilities model and the categorization of its solutions in order to identify the appropriate rules that will allow us to give our system its adaptive quality.

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