# Learning Games for the Cognitively Impaired People

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## ABSTRACT
Learning environments have been profoundly reshaped by pervasive technology. New educational methodologies take full advantage of ICT in a mobile customized user-friendly environment, to support learning and stimulate individuals' potential. Unfortunately, technology-enhanced learning tools are not often designed with accessibility in mind, although they can greatly benefit the personal empowerment and inclusion of special-needs people. To address this gap, a Web platform has been created for delivering accessible games to people with Down syndrome. Since personalization, orderliness and positive reinforcement are crucial to learning in these subjects, the platform offers a personalized safe environment for learning, conforming to behavioral analysis principles. Learning analytics are incorporated in the platform for easy monitoring of student progress via Web interfaces. The participatory design driving the development of the learning platform allowed the customization of the games' discriminative stimuli, difficulty levels and reinforcement, as well as the creation of a game "engine" to easily set up new personalized exercises. These customization features make the game platform usable by a larger audience, including individuals with learning difficulties and autism.

## CCS Concepts
• Human-centered computing~Web-based interaction • Human-centered computing~Accessibility systems and tools • Social and professional topics~People with disabilities • Applied computing~Interactive learning environments

## General Terms
Design, Human Factors

## Keywords
Computer-enhanced learning, Web Applications, Cognitive Games, People with special needs

## 1. INTRODUCTION
The diffusion of Information and Communication technology (ICT) in the last two decades has reshaped learning environments. New educational methodologies incorporating ICT technologies in traditional curricula elicit and reinforce one's personal learning potential [6, 7, 15, 20].

Anyone can benefit from this technological potential. However, for people with learning difficulties, the use of computer-enhanced systems offers an extra opportunity to improve their personal skills and educational performance. Software applications can help compensate for a disability deficit facilitating the individual's life and encouraging the subject's autonomy, with social and economic benefits for the whole community. As shown by Hasselbring et al., students with learning disabilities often pay more attention when working on multimedia computer-enhanced activities than on classic ones [12]. Computers help capture attention, allowing people with attention deficit to focus on the task [23].

Life expectancy in individuals with Down Syndrome (DS) has greatly increased in the last few decades. The number of adults with DS aged over 40 years has doubled in northern Europe since 1990 [24]. Adults with DS show a strong susceptibility to developing early-onset Alzheimer disease and about two-thirds of them develop dementia by the age of 60 [24, 26]. To delay the onset of dementia, brain training is crucial to sustain cognitive abilities, maximizing the rehabilitation time. To this aim, we have developed a Web platform for delivering personalized accessible games to individuals with DS.

The platform provides a learning environment that trains the subject to improve or maintain abilities such as attention, memory, visual-spatial orientation, temporal orientation, pre-logical and logical operations, perception, visual analysis, etc. It provides people with DS a tele-rehabilitation tool available anytime, anywhere as an enriched environment to train their brain and contrast dementia. The game relies on augmentative and alternative communication (AAC), an assistive technology commonly used in the treatment of cognitive impairment [25]. AAC uses images, video, gestures or other forms of communication as an alternative supplement to the auditory channel. As in DS people the visual-spatial memory is stronger than the auditory-verbal memory [5, 8], the emphasis is on the visual aspect. Data collected from playtime interaction are searchable through a learning analytic tool for monitoring the user's progress over time.

The paper is structured in seven sections. Section 2 introduces related work, Section 3 describes the platform design, Section 4 details the games while Section 5 summarizes the main results of a Pilot Test conducted with two users. Conclusions end the paper.

## 2. RELATED WORK
Several studies investigate the impact of Cognitive Learning Games (CLG) on perceptual and cognitive skills, highlighting that players exhibit a range of attention and visual perceptual advantages compared with no-game players. Green and Bavelier (2006) evaluate the ability to track items on the screen, confirming that playing action video games enhances the number of objects that can be mastered, and suggest the role of changes in visual short-term memory skills that produce this enhancement [11]. Boot et al. [6] examined both


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expert/non-gamer differences and the effects of video game playing on a wider range of cognitive abilities, including attention, memory, and executive control. Results confirmed that action video games modify visual selective attention. The positive influence of games on cognitive skills is also suggested by Feng et al. [9] and improved in spatial abilities in female subjects using action video games designed ad hoc has been observed by Terlecki [21]. The impact of a computerized visual-spatial memory training intervention on memory and behavioral skills has been recently investigated by Bennet et al. After a training session with 21 children with DS, aged 7-12, performance on visual-spatial short-term memory tasks (trained and not) was significantly enhanced for subjects in the intervention group [15]. Kirijian et al. [14] reported helpful suggestions regarding type of images, animation, sounds, font and colors to use to create an attractive learning environment for DS subjects. All these suggestions were taken into consideration when we created the software platform described herein. However, to the authors' knowledge few studies are available in the literature for training DS adults in order to prevent the development of Alzheimer's Disease (AD) [1].

# 3. PLATFORM DESIGN

In a previous study [1], we created an app for cognitive training of adults with DS, with the aim of delaying the possible onset of dementia. Based on the knowledge and experience gained, we have designed an integrated, highly configurable and adaptable platform able to match the needs of a wider audience, including adults, children and adolescents with DS. Down syndrome, by definition, combines multiple clinical manifestations so it is quite difficult to address specificities of each individual. Identifying main distinctive traits within the syndrome it is possible to develop a virtual environment offering different types of games to match memory, attention, motricity and other needs. The support of psychologists and doctors involved from the earliest steps of the study has been crucial for creating a usable and effective rehab tool. The main software goals were the creation of cognitive games with increasing/decreasing levels of difficulty, to dynamically adapt the trial flow to the subject's responses, decreasing their stress and favors autonomy in the self-rehabilitation. Furthermore, to easily assess the subjects' learning trend and refine training programs, a dashboard for psychologists and caregivers was created.

To meet these requirements, the developed platform exploits Web 2.0 benefits to assure continuity of intervention (home/school), content customization, adaptation, multimedia interaction, full control of learning content, data collection and easy profile access (student/teacher). These features enable the creation of a tele-rehabilitation platform, which offers online training. According to several authors investigating the positive effects of psycho-physical training in different pathological situations including DS [2, 3, 4, 13, 16, 17, 19, 22], it is fundamental to maximize the rehabilitation time. Moving from face-to-face to a remote technology-enhanced therapy (via computer or tablet) offers advantages in terms of cost reduction and time saved, alleviating the burden on families and the health system. Subjects can exercise their brain more comfortably at home, independently and at their own pace. The electronic device provides agreeable stimuli and foreseeable actions, and the independence and success may stimulate the subject to increase the training time. In this way, tele-rehabilitation can empower a DS person, taking full advantage of her/his abilities.

The CLG platform is a Web-based environment with a typical stack model LAMP (Linux, Apache, MySQL, PHP). This service model satisfies the ubiquity requirement of the learning platform. The software adapts the UIs to different screen rendering, allowing the device's independence. Furthermore, using free software as a component, it is guaranteed to be globally free and open source. The architecture reproduces a typical RIA (Rich Internet Application) using Web technologies such as AJAX and JQuery, both for page flow management and user interaction control, as well as for sending and receiving data in synchronous and asynchronous modality. The application is supported by a database designed ad hoc and accessible through an internal module (DAO, namely Data Access Object) entirely written in PHP. The DAO module is composed of two levels: core and services. The services make extensive use of JSON as data transport format and can be called directly from the server components or via *http* through AJAX calls. This choice allows responsiveness to user interaction, offering portability, power and speed at the highest levels on the client device.

## 3.1 Platform UIs and Functions

The CLG platform is available in two modalities, public or via login. The registration mode takes full advantage of its additional functions: personalization, data collection and analysis. However, all the educational games are freely available to unregistered users. This choice enables users to explore the application and assess its potential benefits before registration. CLG platform is able to adapt to the teacher's needs providing them the possibility of uploading personalized content, creating customized games and assigning the most suitable list of games for each student.

Performance data were collected automatically during playtime. The application offers tables and charts that could be helpful for statistical interpretation of the learning trends (an example is shown in Fig. 1). Data can be exported in CSV format for post-processing.


Fig. 1. Example of student's performance chart over time

After the login, the Student UI provides access to the games (public or customized). If the student is logged-in, during the playtime the system records session data asynchronously in a fully transparent way.

# 4. THE GAMES

Exploiting the new features introduced in HTML 5, we have used the tag canvas, audio and video that allow implementing game applications providing adequate user interactivity on the Web, without the need for external plug-ins such as Adobe Flash.

Cognitive Learning Games are helpful in engaging perception, memory and thinking processes. In addition, since they also rely on luck, it seems to activate decision-making processes [10, 18]. The game application is written in JavaScript without depending on external packages and it is organized on two levels: *(i)* A library of "game objects", **Game Object Library**, designed to provide a common set of features and the objects to be used in the game design. *(ii)* A **game-engine set**; a game-engine allows one to create different version of the game using the Game Object Library.

The **game object library** defines a set of objects that can be assembled to create a specific game. All the objects in the library are designed according to an "object-oriented" model. Some objects perform simple graphics procedures, others can interact with the user input (mouse and touch). In the latter case, when it is created, the objects trigger a listener for all events that have to be managed along with a specific handler, different for each event. For instance, an object defined as "*draggable*" implements *event handlers* that enable them to be able to be dragged and dropped onto the two-dimensional grid of the canvas. The library objects are of two types: a) Graphic objects, or objects that can be "drawn" into the canvas; ranging from simple geometric shapes or text to bitmap images; b) Layout objects, or collections of graphic objects, geometrically arranged on the canvas area. The layout objects have the ability to automatically adapt their geometry to the screen, reducing the programming effort required to adapt the objects' size to the screen size every time.

A **game engine** is an object that implements game instances. Currently, we have created an initial set of five cognitive games/activities:

**Logical Sequences**: the student must reconstruct a logical sequence of images by sorting them. The game offers sequences of increasing levels of difficulty.

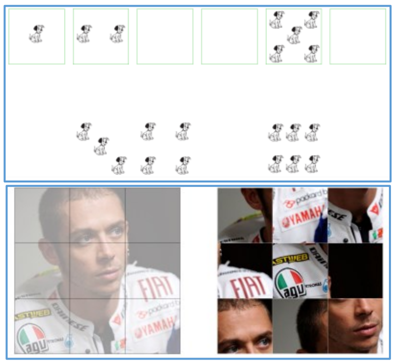

Fig. 2. Game screenshots: Logic Sequences, Puzzle

**Puzzle**: it starts with a minimum subdivision of a picture (four pieces) and proceeds to levels of increasing difficulty. The number of possible subdivisions is customizable.

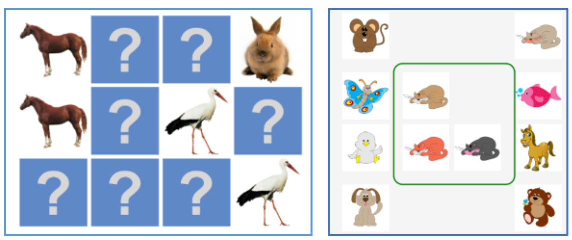


Fig. 3. Game screenshots: Memory (4x3 elements), Families

**Memory**: the classic game of Memory (to find and match couples of images), progressing through levels of increasing difficulty.

**Families**: A set of family items in common categories (e.g.: dogs, horses, cats, etc.). The user has to drag the target element to complete the family currently proposed.

**Video modeling**: allows to learn the steps (sequences of actions) composing every day activities, favoring autonomy.

Each game implements a specific algorithm (one for each game) to calculate the player success score to record. This success score, within the same game, depends on the correct and wrong player moves, on the prompts (helps) used and also on the difficulty level.

The games per se are similar to those available on the App stores and the Web, which are well known to Internet users. Furthermore, we have enriched the game experience via the following aspects:

1. The design game and the UIs are multimodal, allowing different types of users to better understand the task (presence of vocal or text inputs depending on the user preferences).
2. Demo and help (prompt) commands can be easily activated.
3. The platform implements the error-less principle of the behavioral approach. However, if the student is performing an error, although the system does not allow it to be completed, the platform correctly records the user attempt as an error in the performance data.
4. Content used for designing each game could be personalized.
5. The game's level of difficulty is tuned depending on student responses.
6. Data on the user actions for each game are stored on the database, so the student's performance can be monitored over time in relation to the proposed learning path.

## 5. PRELIMINARY PILOT TEST

After the development of the prototype, a pilot test was performed with two adults with DS in order to refine the software functionalities and improve the user interfaces. The pilot was carried out in two different sessions, one for each tester. The first participant was a female aged 32, L.; the second a male aged 28, J.

Before the test, the users answered a questionnaire containing general and demographic information, then, a researcher described the platforms illustrating the main functions and showing a demo for each game. Next, the user was invited to play sequentially with one of the games: Logic sequences, Puzzles and Memory games. After each game, the user was invited to answer an online questionnaire containing usability information and personal suggestions in order to collect feedback to improve the game. After each game, we proposed a 5-minute break.

The first participant works in a research Institute in Pisa where she performs autonomously simple tasks including correspondence sorting and data entry. Since she expresses Down syndrome mildly (showing the best QI rate among people with DS in Italy), we have considered her suggestions as a value complement to our participatory design in order to acquire more insight into the preferences and potential of this special-needs population. The second participant works in Lucca at a swimming pool, with a good degree of autonomy in performing simple tasks. He is collaborative and likes to use computers and play games.

The first participant (L.) was actually able to provide us with feedback both directly, answering to our vocal questions and filling in the online usability questionnaire, and indirectly, allowing us to derive valuable information by observing her behavior. She frequently expressed unsolicited opinions and suggestions during the pilot test, and appeared very engaged, refusing the pauses. She suggested enriching the image database content with popular artists, sportsmen/women, musical groups, protagonists of fairy tales, paintings, etc.) to be used by the platform. Results reflected the high cognitive functioning of the tester: she executed the trials autonomously, without prompts and adopting smart strategies. The execution time was shorter than that of the second participant. Nevertheless, games requiring drag and drop (puzzles, sequence and families) required a longer time because L. preferred to perform them attentively positioning each element precisely in the space provided, although she was informed that she could be less accurate due to the presence of an attractive region able to capture the target element.

Both participants received the platform enthusiastically, appreciating the attractive images and the challenge of the increasing level of difficulty of the games. The first participant was attracted by the challenging nature of the games and reinforced by her success. She declared: "I like to play with games asking for increasing ability". Games were perceived, by both users as active entertainments and not as tedious tasks.

## 6. CONCLUSION

In this paper, we have presented a Web platform for delivering accessible games to individuals with Down syndrome. The platform offers a personalized safe environment for learning, conforming to behavioral analysis principles. Learning analytics are incorporated in the platform for easy monitoring the student progress via Web interfaces. The flexibility, personalization and focus on the individual's potential and limits make the proposed educational platform a safe and cheap tool, completely free and open source. These customization features make the game platform usable by a larger audience, including individuals with learning difficulties and autism.

A pilot test with two adults with DS underlined their interest in the game platform and the pleasant aspect of the user interfaces, allowing us to refine the platform content database.

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