Implementing Accessibility in Educational Videogames with <e-Adventure>

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ABSTRACT
Web-based distance education (often identified as e-learning) is being reinvented to include richer content, with multimedia and interactive experiences that engage the students, thus increasing their motivation. However, the richer the content, the more difficult it becomes to maintain accessibility for people with special needs. Multimedia contents in general and educational games in particular present accessibility challenges that must be addressed to maintain e-learning inclusivity. Usually the accessibility of multimedia content in courses is addressed with the definition of simpler but more accessible content that diminishes the benefits of the richer content. Hence we need new, accessible multimedia technologies that guarantee that the learning experience is motivating and engaging to all students. We will focus our work on educational games, trying to leverage their engaging narratives to produce educational experiences that are attractive to all students, including people with special needs. Nonetheless the development of accessible games is a major challenge, due mostly to the additional development cost it involves. In this paper we present how the <e-Adventure> game platform facilitates the development of educational videogames for e-learning, simplifying the introduction of accessibility from the design stage of the game development process.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *auditory (non-speech) feedback, graphical user interfaces (GUI), natural language, screen design*;

K.3.1 [**Computers and Education**]: Computer uses in education – *distance learning, computer-managed instruction*;

K.8.0 [**Personal Computing**]: General – *games*.

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D.1.7 [**Programming Techniques**]: Visual programming;

General Terms
Design, Economics, Human Factors.

Keywords
Accessibility, <e-Adventure>, e-learning, distance learning, game authoring tools, game-based learning, online learning, videogames.

1. INTRODUCTION
For the last decades, information systems in general and the Internet in particular have experienced rapid expansion. These systems have become a fundamental tool in daily life, but this advance sometimes signifies a marginalization for people with special needs who cannot access the content that new technologies provide (be it as a consequence of personal characteristics or contextual issues). This has caused an increasing effort in the development of the technologies that enhance the accessibility of information systems for people with special needs.

Nevertheless, the creation of accessible technologies has focused unequally on different fields of software development. While the accessibility of websites is reasonably covered, other areas such as interactive multimedia (and especially videogames) are still trying to find the most suitable way to create accessible products. While it is true that there are some videogames that include accessibility characteristics, the high cost involved in acquiring some of these features is hindering their widespread adoption. One of the possible interventions is to provide all the information, even the small details, through several alternative channels at the same time, which is usually achieved by combining subtitles and sound/voices. However, this approach requires a considerable investment in gathering all the audio recordings (a videogame may have hundreds or thousands of information lines), which often makes this approach unaffordable in contexts where the budget is limited.

These problems are especially important in educational videogames. The need for enhanced accessibility in any kind of educational content is more pressing than in purely entertainment-driven developments (and even more in e-learning environments).

According to the 2007 US Census Bureau[1], 18% of the US population and 11% of children from 6 to 14 have some level of disability, with 12% of the total population having a severe disability. If videogames are to play a role in education, accessibility cannot be left aside. In addition, the higher cost of accessible games is harder to assume in an educational videogame, given that most educational gaming projects often have a limited budget, which makes the issue far more serious. These contexts require methodologies, design patterns, and tools that facilitate the creation of accessible videogames, without compromising the cost. In contrast, a survey of the domain reveals that such elements are rare and have received scarce attention in the literature.

In fact, game-based learning is still an emerging field being discussed in academic environments, with both supporters and detractors [1]. Therefore, developers are still more concerned with creating appropriate games for learning than in making them accessible, assuming that accessibility could be eventually addressed in the future. However, we consider that educational videogames, and especially web-oriented games, should take accessibility aspects into account from the very beginning if they are to become a real alternative or complement to other educational approaches.

The aim of our work is to create a system based on natural language processing to allow the introduction of accessible features in the development of educational videogames without compromising development costs. The system offers different pre-made input/output modules such as a voice interface for recognizing voice commands, a text interface for recognizing text orders, and a voice synthesis module for transmitting audio feedback without additional development efforts. The system has been integrated into <e-Adventure>, a game authoring platform designed to facilitate the creation of educational *point-and-click* adventure games for e-learning environments.

This work is structured as follows: Section 2 provides some context, focusing on the potential issues and current trends in accessibility, games and education. Section 3 describes a general framework for web-oriented accessible games in education, which has served as a base for the integration of accessibility features into the <e-Adventure> platform, as described in section 4. Section 5 presents a concrete case study, in which a pre-existing game is enhanced with accessibility features using <e-Adventure>. Finally, section 6 presents some conclusions and future lines of work.

2. CONTEXT: ACCESSIBILITY, GAMES AND EDUCATION

The accessibility of information systems is rapidly becoming a key issue, since it is one of the potential sources of digital division. In this context, the accessibility of educational technologies can seriously affect the future opportunities of individuals with limited means of access. While traditional teaching methods are often able to cope with accessibility aspects (often through the effort of dedicated instructors), the current trend towards increasingly complex educational technologies is continuously growing the challenge.

[1] http://www.census.gov

2.1 Web Accessibility

The emergence of the World Wide Web (WWW) and the posterior interest in e-learning environments was initially disruptive in this sense, leaving students with special needs unable to access these systems. Screen-reading tools partially resolved that issue. However, parallel to the evolution of the Web, e-learning environments grew more complex and started to include advanced multimedia content that increased the importance of accessibility measures.

To that end, these e-learning web-based tools can benefit from the ongoing efforts fulfilled by different public and private organizations to improve WWW accessibility. Highly influential organizations as the W3C are presenting the necessary requirements to create accessible web content [2, 3], along with webmaster-oriented tools to check the accessibility of web-based content [4].

There are also initiatives that specifically deal with digital educational contents for web environments. A very thorough approach was undertaken by the IMS Global Consortium in their *IMS AccessForAll* set of specifications [5, 6]. Unfortunately, these efforts are principally focused on the most common types of educational content (including many forms of multimedia content), but do not adequately cover highly interactive content such as educational games.

2.2 Input Device Adaptation for Videogames

The most common approach to increasing the accessibility of videogames is to seek their compatibility with assistive technologies [7]. Some examples would be screen-reading tools, mouse emulators or virtual keyboards. There are also tools that can be used to substitute the usual gamepads provided by game consoles (e.g. vocal joysticks or tongue sensors).

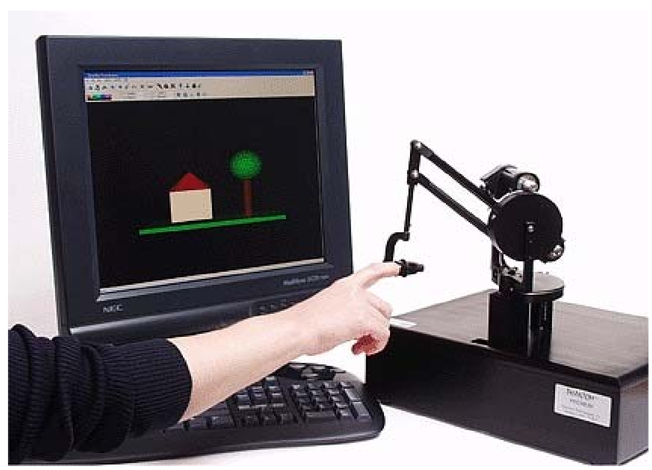

Fig 1. The *PHANToM™* device, created by SensAble Technologies Inc.

In this line, the work presented in [8] shows the use of the *PHANToM™* device (Figure 1), as an example of how *haptic* devices (which provide human-computer interaction based on body movements and the sense of touch) can increase accessibility. This approach not only facilitates access to the games for a wide range of people with impaired mobility (controlling the videogames with easy movements of one finger), but can also be useful to visually impaired people because the device offers them the possibility of perceiving 3D objects by means of movements of a device.

Another approach consists of adjusting the games without requiring specific devices (e.g. adding subtitles). However it is possible to bring both conceptions together. In this line we find *auditory games*, (also known as "audio - games") [9] which are specially designed for people with visual impairments, where the information from the game is transmitted through audio [10]. In some of those games the indications are given with abstract sounds, but the games with major acceptance are those which give users voice descriptions reproduced through text synthesizers.

Another way to provide audible information is with descriptive sounds. Specific sounds, which are used intensively throughout the game, are given special meanings so it is easy to remember the association between sounds and meanings. Other games receive input through voice or by means of specific devices [11].

2.3 Methodologies, Tools and Design Patterns for Accessible Videogames

Other works, such as [12], have focused on providing some design guidelines such as how to design interfaces or some simple methodologies for accessible videogame development [9, 13]. There are also design patterns and web initiatives providing indications on how to create accessible videogames, although they have not been translated into broadly accepted standards or specifications yet.

The *International Game Developers Association* (IGDA) has a *Special Interest Group* that focuses on accessibility issues[2] and published a white paper which provides a good analysis of the field [14]. This document provides a general overview, covering what accessibility in games means, why it is necessary, and what kind of disabilities can be tackled at the videogame creation stage. That work also gives some indications about how to adapt an already created game to improve its accessibility through adding subtitles and customizing text fonts, or how the textual information and subtitles can be recorded or synthesized. Along with these ideas, they encourage the use of other approaches to gather user input such as use voice recognition or other specific devices. However, the report does not propose any concrete pattern or methodology to create accessible games.

A unique approach from a technological point of view is proposed by *FORTH* (Foundation for Research and Technology - Hellas) [13], and is based on the *Unified User Interface Design* (UUID) [15]. UUID proposes a design pattern where the game tasks are initially considered in an abstract device-independent way. In later design phases, the interaction for each game task is designed and includes the selection of input/output devices. Several games have been developed following these guidelines, achieving accessibility for people with a wide range of special needs. These are the universally accessible games (*UA-Games*). An example is *Access Invaders* [16], which supports different game settings depending on the potential disabilities of each player, such as blindness (in which case the game will be loaded with the appropriate characteristics of the Audio-Games), damaged vision, cognitive disabilities or motor disabilities.

[2] http://www.igda.org/accessibility/

As far as development tools are concerned, the market is populated with many authoring environments for the development of videogames. There are development frameworks for game programming (such as *Microsoft XNA™*[3]), game development environments which allow people without technical knowledge to develop their own videogames (like *Game Maker*™[4] or *Unity3D*™[5]) and even simple editors oriented to specific game genres like *The FPS Creator*[6] or *Adventure Game Studio*[7]. However, none of these initiatives includes pre-configured features targeting game accessibility. This means that accessibility has to be implemented from scratch for every individual game.

2.4 Accessibility in Commercial Videogames

There are some commercial videogames that implement features to enhance accessibility or that have been modified after being published for this purpose. The creators of *Half Life 2*™ introduced accessibility for people with hearing problems during the development process after they received some complaints concerning the first issue of the saga. The reason is that in *Half Life*™ certain information that was essential to complete the game was transmitted across cut-scenes (videos) without subtitles, making it impossible for people with hearing impairments to reach the end of the game [17].

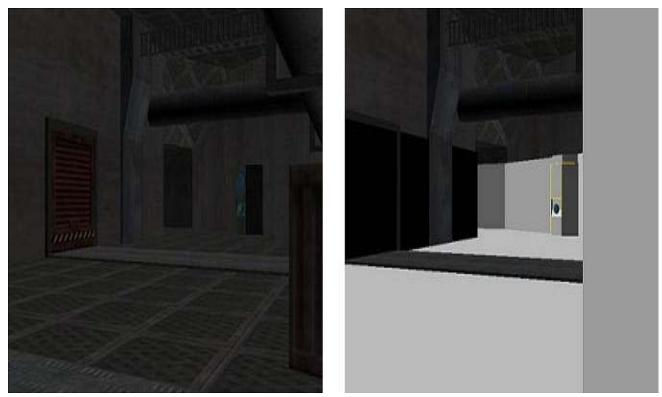

Fig 2. *Terraformers* game: left image shows normal mode, and right image shows the same scene with high contrast.

Terraformers™ was directly designed with accessibility features at an early stage. It includes a normal mode in which visual graphics are reproduced as usual in first-person 3D games, but it also has an accessible mode. In that mode, a sonar is activated to tell players what is in front of them and the contrast of the graphics is increased for vision-impaired people [18]; this mode also allows the player to select objects from the inventory orally.

3. DESIGNING ACCESSIBLE VIDEOGAMES FOR E-LEARNING

There are several considerations that must be taken into account when designing accessibility for a videogame. If the game is to be embedded in an e-learning scenario, some additional peculiarities

[3] http://www.xna.com/
[4] http://www.yoyogames.com/make
[5] http://unity3d.com/
[6] http://www.fpscreator.com/
[7] http://www.adventuregamestudio.co.uk/

must be considered. For instance, dealing with cognitive impairments, which is rarely covered in entertainment-driven videogames, becomes a very important issue in education as cognition and learning are closely related. In this section we will discuss these and other general considerations. First we will discuss the user model to be used to model the needs of each student (that is, what the user can or cannot do). Then we will discuss what to adapt in the games according to the user model. Finally we will discuss some other relevant issues such as the choice of appropriate game genres.

3.1 Input Data for Accessibility. User model definition

The first issue that must be considered when designing accessibility for a videogame is to identify the data that will serve as input to adapt the game. The most obvious (and probably most important) is the *user model*. That is, what the system knows about the user. This is a crucial factor as the game will need to know what the special needs of each student are in order to adapt the game experience.

But adaptation cannot be limited to students' impairments that are not expected to change over time. Even though the term accessibility is usually associated with personal disabilities, it can also be a result of the environment (i.e. context). A hearing impaired person is as challenged by audio content as any other person in a loud environment without earphones. Therefore the *environment settings* must also be taken into account. The adaptation will be more effective if the input data provided is focused on *what the user can or cannot do in that precise moment and context.*

The user model should also include some *user preferences* that may help to make the game accessible to the student, including *preferred and forbidden settings*. This is indispensable to facilitate access to the games for students with "minor" needs that might not be able to play a game due simply to small details that could be easily fixed by adapting the configuration of the game slightly. If students are able to play the game but only with great effort, they could get frustrated after a while. For instance, color-blind students may not be able to read a text or recognize an enemy approaching when a specific combination of colors is used.

Most of the information about accessibility that the user model should contain can be classified in four categories according to the group of impairments of a particular student in a particular context. Those are visual, hearing, mobility and cognitive impairments. Table 1 represents a fragment of a simple user model, including a categorization of the user (compulsory) and some preference attributes (optional) under each category. Although this is a simplified example, it illustrates some of the most relevant situations.

Table 1. Accessibility-attributes for the user model

Group	Attribute	Accepted values
Visual impairments	Vision level	*Low-vision* (unable to read normal text but who would be able to read it with some aids); *Complete impairment* (unable see anything on the screen).
Visual preferences	Preferred color combination	Preferred text and background colors for the student
	Forbidden color combination	Text and background colors that would impede or make the student's access to the game the difficult.
Hearing impairments	Hearing level	*Low hearing* (able to hear background sounds, requires subtitles for conversations); *Complete Impairment* (requires full subtitles for every event)
Hearing preferences	Preferred sound level	0-100
Mobility impairments	Hand-arm mobility level	*Difficulties using mouse*; *Difficulties using keyboard*; *Cannot move hands*

Note that, as previously indicated, this information is not fixed for each student and can change in runtime to cover environmental or context issues.

3.2 Maintenance and Persistence of the User Model

An important design issue is how (and when) to produce and maintain the data that will be used for accessibility. For a desktop game, the persistent data about the user can be obtained directly from the student when the game is installed, by storing the information on disk for further execution of the game (or other similar games). In these cases, the student is responsible for providing and maintaining the information.

In some other games, the instructor may be aware of the special needs of a group of students, and pre-configure the game before distributing it to the students.

Finally, in web-based e-learning environments, it would make more sense to keep the data about the user in a central location independent of the student's computer. The current e-learning environments have evolved into the so-called Learning Management Systems (LMS), such as *Moodle*™, *Sakai*™ or *Blackboard*™, with features far more sophisticated than the initial content repositories used in web-based e-learning. A modern LMS stores information about the students and their progress, and can deliver customized information to each client. These systems can thus store the user models centrally and deliver it to the clients each time the game is executed.

Thus, depending on the context, the user model may be maintained by the students themselves, by the instructor, or stored in a centralized location, with all three approaches presenting different advantages for different scenarios. However, environmental restrictions cannot be computed a priori in any approach. These restrictions should either be automatically inferred or introduced by the student at the beginning of each execution of the game.

3.3 What to Adapt

An accessible game will require some modifications that typically will be different for each user and context. However, in most cases, the adaptations focus on game-user interaction channels. That is, the *input* and *output* systems of the game. Since a game is mostly an interactive experience, these adaptations can pose a significant challenge.

The multiple input/output scenario forces game designers to design game tasks and activities in a device-independent manner [13]. All the aspects of game design must be considered abstractly, with no explicit or implicit binding to any input/output mechanism.

Adapting input and output systems in a game could involve two different tasks. Sometimes it would require providing alternative input/output systems according to the user and environmental models previously defined. The game will decide at runtime what input/output alternatives are used. This is the typical case for visual, hearing and mobility impairments. To design these alternatives methodologically, game designers first need to think about the input/output system that will be provided for each attribute. Then they need to define the input/output systems that will be enabled or disabled in any case.

However, in many other cases, accessibility issues can be addressed by simply adjusting some game parameters. Some "minor" visual, hearing and mobility impairments will fall into this category. For instance, people with reduced hand mobility may not be able to control a mouse or the keyboard fast enough to cope with the quick reaction times often found in action games. In these cases, it would be enough to adjust the time pressure to allow impaired students to interact with the game at their own pace.

Nevertheless, there are cases where adapting the input and the output will not be enough and the own game structure will require adaptation. Cognitive and mental impairments may require lessening the difficulty of the game, skipping some activities, adjusting the text or speech speed, etc. Just as happens with other educational approaches, this is the most challenging accessibility adaptation, and possibly requires changes in the core of the game experience. These challenges are difficult to address in a systematic manner, and the specific approach will be dependent on the specific topics presented by the game.

3.4 Deciding the Game Genre

Accessibility requirements are very different depending on the game genre. In educational gaming, game genre is always a crucial factor, as not all games are equally appropriate for learning. Given that some game genres are more suitable for accessibility than others, the choice of a game genre becomes even more relevant.

As described in the previous, activities in games must be designed abstractly without committing to any specific device or input/output system. Thereby, when possible, it is better to focus on game genres where engagement and immersion are obtained thanks to the attractiveness of game tasks, activities and the flow of the game itself, moving away from some features such as being visually attractive or providing intensive action. Educational games must capture the attention and motivate students even when their accessibility features are activated. Otherwise, their positive effects for learning will be lost.

Point-and-click adventure games, such as the classic *Monkey Island*© or *Myst*© sagas, meet these requirements. This kind of games captures the players' attention by developing an engaging and motivational plot narrative that players unblock as they advance in the game. Graphics, sounds, or special effects are part of these games as well, but only as peripheral features to enhance immersion in the game. In addition they promote reflection instead of action, which is very convenient for people with motor impairments, who have plenty of time to solve puzzles with no time pressure. Besides, *point-and-click* adventure and story-telling games are especially adequate for education [19]. In our opinion, adventure games are a good candidate when planning the development of an accessible educational game, as they are adequate both for educational purposes and for introducing accessibility.

3.5 General considerations

Finally any development of an accessible game must be carried out following some general design guidelines. The adaptation that is performed in the game must be as user-customized as possible. If different alternatives may be feasible for a certain kind of disability, the optimum one must be chosen, while considering aspects such as which one best preserves engagement and immersion factors in the game or which alternative will make the game less effort-consuming for people with that disability. A possible methodology to achieve this would be completing a cross-table that matches all the possible disabilities identified in the user model with all the possible adaptations, indicating if each option is optimum, valid or not valid at all [13].

Besides, settings in the game must be as flexible as possible. Either by direct action of the user or by automatic inference, the game should permit the easy configuration of the text font settings (color, size, etc.), audio settings, time response gaps, and input/output settings (e.g. screen size and resolution).

Another important consideration is that an accessible game must always be compatible with adapted input/output devices, especially if the game is to be accessible to people with severe mobility impairments.

Tutorials on how to use the games for each possible adaptation setting must be designed, implemented and embedded in the game to ensure that all the students will be able to play.

Finally, how the game is going to be delivered, installed and accessed must be considered as well. Accessible games should be extremely easy to install and execute. In e-learning settings we can take advantage of the web to deliver and distribute the games. Accessing a game that is embedded in a web page would be easier for students with special needs as it does not require any installation and they usually have hardware or software aids to navigate the web.

4. THE <E-ADVENTURE> APPROACH

We have implemented the ideas presented in this paper in the <e-Adventure> platform. <e-Adventure> [20] is an educational game platform developed by the <e-UCM> research group at the Complutense University of Madrid (Spain) which has been used in the development of several educational games [21, 22]. The platform is composed of two applications: a game authoring editor (used to create the educational games) and a game engine (used to execute the games). The editor is completely instructor-oriented; hence it does not require any technical background or programming skills to be used [23].

The platform has some features to facilitate accessible game development, especially for e-learning applications. First, it is focused on the *point-and-click* adventure game genre, which is one of the specially suited types of games for accessibility, as discussed in section 3.4. As well, <e-Adventure> provides instructors with special features that enhance the educational possibilities of the platform, including a mechanism to adapt the game experience to the needs of different students [24]. These adaptations can focus on adapting the content (to suit different learning objectives or different levels of initial knowledge) or adapting the interaction modes to support users with special needs.

Finally <e-Adventure> games can be deployed via web and integrated with an LMS [25], which makes the platform ideal to integrate accessible educational games in e-learning courses.

4.1 General Architecture

The <e-Adventure> platform includes several *pre-configured input/output modules* to facilitate the inclusion of accessibility in the games. The idea is that game authors should be able to define various interaction mechanisms that coexist in the game, so that people with special needs can play easily. In addition <e-Adventure> includes some *in-game tools* that can be included in the games as an aid for impaired people. These modules are activated/deactivated by means of a user model.

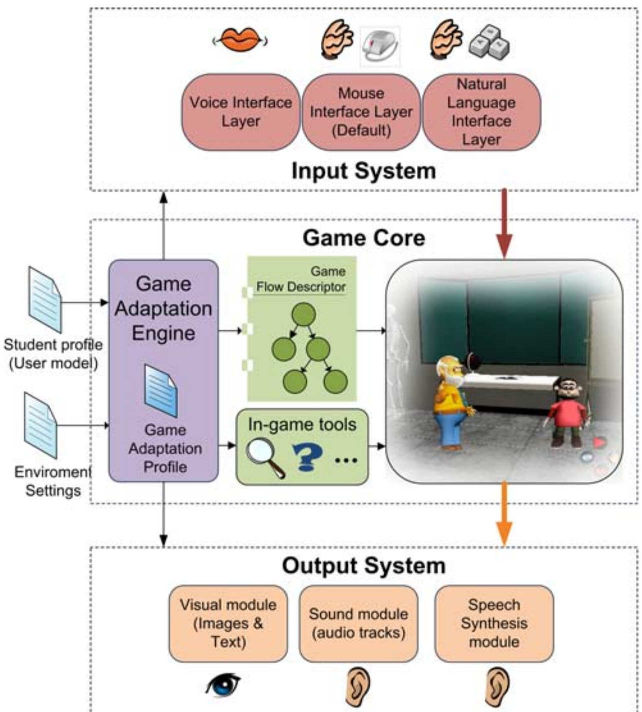

Fig 3. Architecture of the game engine (game application).

<e-Adventure> contemplates a user model which contains information about the student. The game engine expects to receive a user model which can be integrated with the game through the <e-Adventure> editor, imported from the e-learning environment or gathered from the student before the game starts. The model is separated into two parts. The *student profile* contains all the information concerning the permanent special needs of the student (i.e. things that are not expected to change in time such as the impairments of the student). The *environment or context settings* describe circumstantial needs that are related to the scenario where the game is going to be played (e.g. the environment is noisy or sound is not allowed) or momentary special requirements of the student (e.g. the student has a broken arm). Next sections present in detail all the input/output modules in the <e-Adventure> platform.

4.2 Description of the Input/Output Modules

The input modules supported by the <e-Adventure> platform are three: the *Mouse Interface* module (MI), the *Voice Interface* module *(VI)* and the *Natural Language Interface* module *(NLI)*.

The MI is the classical interaction mechanism in *point-and-click* adventure games, where students usually need to point the mouse over NPCs (Non-Player Characters) and objects they find on their way in order to trigger any kind of in-game interaction. Therefore students need to be able to move the mouse and to see the elements on the screen in order to play the games, which may make them inaccessible to students with visual or mobility impairments. The VI is controlled by speech so students only need to be able to speak to control the games. Using a microphone, students can directly “give orders” to trigger any interaction in the game (e.g. “go to the library” or “grab the notebook”). The VI does not depend on the student’s voice to work so students do not need to train the system, which is always an excruciating task. Besides, the VI accepts diverse synonymous orders for the same action (e.g. examine the scene or describe the scene) so students do not really need to learn how to use the VI, which is a typical problem in voice recognition. Table 2 shows an example of typical orders that the system would recognize in an <e-Adventure> game.

Table 2. Example of natural language commands that the VI and NLI modules recognize

Order	Description
Examine the table	The game will provide a description of the object “table”, if it exists in the scene.
Go to the left	The student’s avatar in the game will move in that direction, discovering new items that were still hidden.
Grab the pencil	The game will take out the object “pencil” from the scene and put it in the student’s inventory[8].
Name items in the scene	The game will tell the student which items have already been discovered so he or she can interact with them.

The NLI accepts the same orders as the VI, but uses the keyboard as the input device. Thus students can interact with the game using text in natural language, which is helpful if students have speech and visual impairments or they are not allowed to speak due to environment circumstances (e.g. at a library). Table 3 summarizes all the input modules according to the special requirements they can cover.

Likewise, <e-Adventure> includes three output modules: the *visual* module, the *sound* module and the *speech synthesis*

[8]The inventory is an element that is usually present in point-and-click adventure games. Players use the inventory to store objects they find on their way and keep them for a later use.

module. The visual module is not only used to print images on the screen (the background image for the scene, for the characters and objects, etc.) but also text. Text is a key element in *point-and-click* adventure games, as most of the information is provided through conversations with other characters which are usually textually represented on the screen. Accessibility could be added to conversations by recording all the dialogues by using the sound module (which can play audio tracks in mp3 format), but it would significantly increase the cost of the games, which is a problem when the budget is very limited (as is usually the case for many educational projects). This is why the speech synthesis module is helpful, as it allows the introduction of accessibility for visually impaired students at a low cost. Nonetheless higher-budget projects can use the standard sound module (which plays mp3 files) for increased sound quality.

Table 3. Summary of input/output modules

Input/output module	**Senses Required**	**Adequate for…**
Mouse Interface		Speech impaired students.
Voice Interface		Visually and/or mobility impaired
Natural Language Interface		Visually, speech impaired

4.3 The Game Adaptation Engine and In-Game Tools

Although adapting the input and output systems of the game can cover several physical or contextual impairments, other students will require different approaches. Such is the case regarding cognitive impairments. In these situations it is the game flow which needs to be adapted. Some students will need to lower the difficulty of the games, skip some tasks, receive additional guidance, etc. The <e-Adventure> platform supports this kind of adaptation through the definition of *flags*, which are used to establish conditions that block or unblock game elements or arcs in the game flow [20]. The game author can define a set of adaptation rules (i.e. *adaptation profile*) using data about the student as conditions (e.g. cognitive impairments in this case).

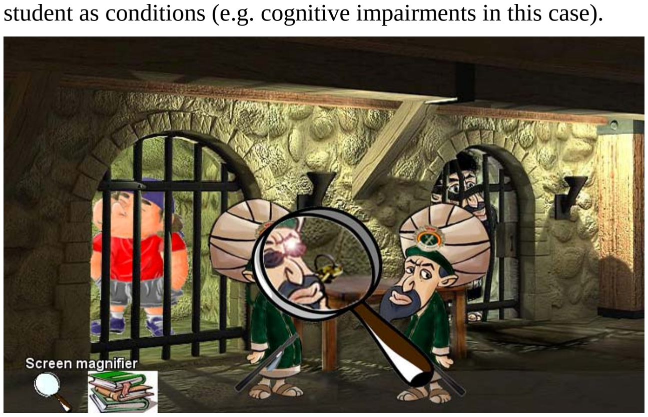

Fig 4. Example of the in-game tool "screen magnifier" in the *1492* <e-Adventure> game.

<e-Adventure> also provides game authors with other interesting tools for accessibility issues. For instance, game authors can provide students with a screen magnifier. To avoid breaking the game-immersive atmosphere, it is represented as an object that is put into the student's inventory (Figure 4). The student can use it to turn the mouse pointer into a magnifying glass that can move around in the game.

In addition, <e-Adventure> allows for a flexible configuration of visual items (e.g. text color) and time interaction gaps, and provides mechanisms for introducing simple hints and aids in the games. All these elements are very effective for making the game accessible to students with slight impairments, such as color-blindness, poor vision or slight cognitive impairments.

All the adaptation processes that <e-Adventure> supports (i.e. input/output adaptation, game flow adaptation and in-game tools) are carried out by a special module in the game engine core, the *Adaptation Engine*. The adaptation engine is configured through the *game adaptation profile*, which defines the set of adaptation rules. This profile includes the definition of the adaptation measures supported by the game, and receives as inputs the *student profile* and the *environment settings* previously described.

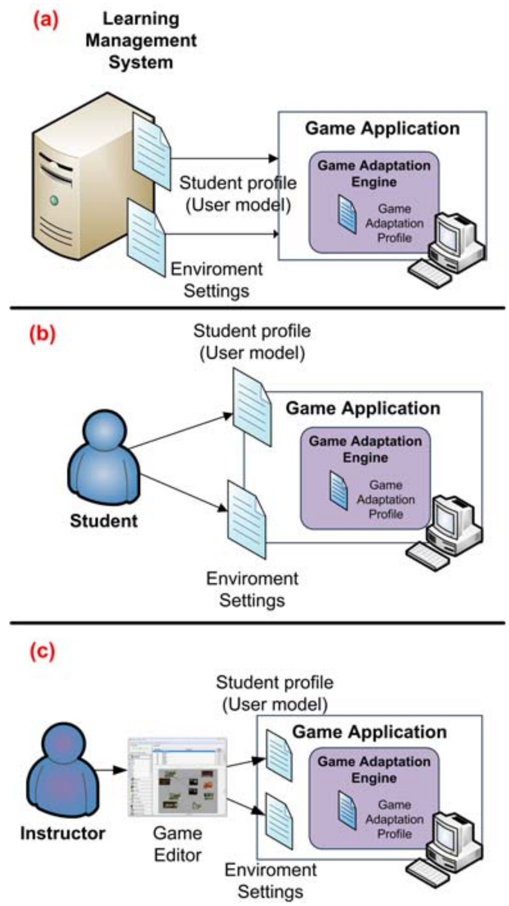

Fig 5. Three different mechanisms for providing input for the adaptation engine

The adaptation profile is defined by the game author, using the game editor just like any other resource file for the game. Therefore it is always distributed within the game package. The inputs that guide the choices from the adaptation profile (student profile and environment settings) can however be received in diverse manners according to the scenarios outlined in section 3.2. Both elements can be defined with the game editor and be included within the game package along with all the other resources of the game (e.g. art assets, game description files, etc.), or they can be delivered by an LMS or introduced manually by the student when the game is executed (Figure 5).

All three input methods are appropriate for different situations, which adds flexibility to the platform. For instance, packaging the inputs along with the game will be adequate for creating standalone versions of the game to be played offline. The inconvenience is that each student with special needs would require that the instructor create a custom version of the game for them. The second option is appropriate for situations where a LMS is available, as the game can be adapted without requiring any intervention of the student. Finally the third option allows game authors to produce a single offline version of the game, but students will need to introduce the input data manually each time they play the game.

4.4 Using the Game Editor to Introduce Accessibility

Authoring an accessible adventure game with the <e-Adventure> game editor is a very simple task. Moreover, the <e-Adventure> game editor can be used to introduce accessibility in existing games with little effort.

The first step is obviously to design and develop the game. It is recommended not to relegate the decision about accessibility to the last instant, but to think about the accessibility features that are going to be introduced in the game during the design phase, especially if they will require adapting the game flow, which would involve providing alternative paths, dealing with difficulty settings or providing additional aid in some situations.

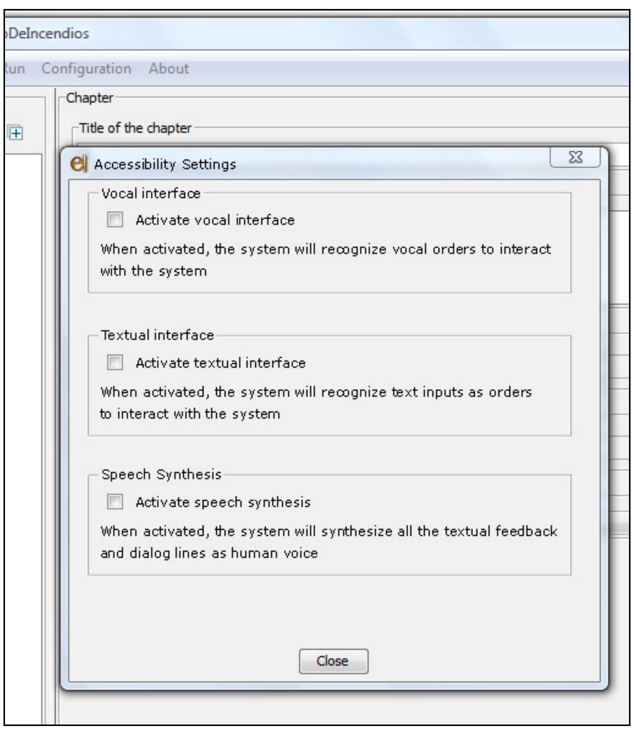

Fig 6. Edition of the Input/Output settings with the <e-Adventure> editor.

When the game is designed, the game authors must select the input/output modules and the in-game tools that they want to be active in the game. The game editor uses these settings to optimize the exportation process so no unneeded modules will be packaged within the game.

If visual accessibility is considered, it is very important that all the visual elements of the game receive an alternative description. When the player enters a scene the game engine will use these descriptions along with some extra information that it computes from the game definition (e.g. number of elements in the scene) to create a complete description of what the student is supposed to see. The complete description is synthesized and played using the audio system.

Finally, game authors need to create the game adaptation profile which will determine under which circumstances the game must be adapted, and how the adaptation must be carried out.

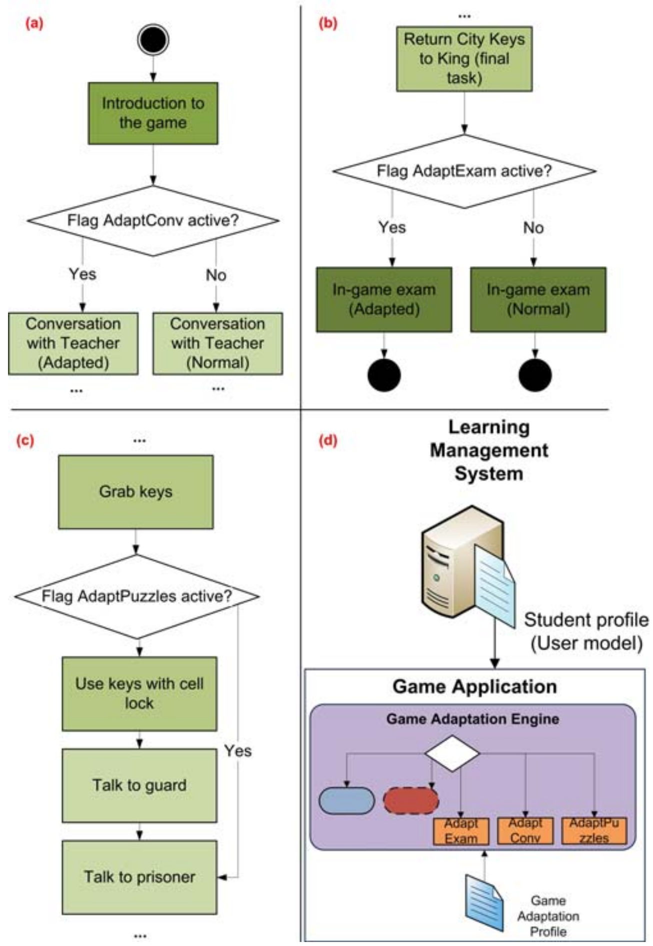

Fig 7. Figures (a), (b) and (c) are examples of how adaptation for cognitive impairments is carried out in the game flow using flags for the game 1492. Figure (d) depicts how the adaptation engine will activate or deactivate flags according to the adaptation rules (game adaptation profile) and the student profile with the disability information (input).

5. CASE STUDY

As a case study to test <e-Adventure> accessibility features we introduced accessibility in a pre-existing game. Following the ideas described in section 4, we introduced accessibility for people with different degrees of visual, hearing and mobility impairments in the game *1492*, an educational game about Spanish history [26]. *1492* focuses specifically on the feats occurring in 1492, such as the discovery of the American continent. These are notable events in the history of Spain, so it is a compulsory subject in primary education, which is an additional, strong motivation to make the game accessible. However, the purpose of the experiment was not to test how the accessibility implemented in <e-Adventure> works in a real scenario with actual students (e.g. check student satisfaction or learning outcomes), but to check its feasibility and effectiveness from a technical perspective (e.g. measure voice recognition accuracy).

1492 was not initially designed as an accessible game. However, it is simple to add accessibility using <e-Adventure>. The first step was to decide what impairments (and what severity level) we were going to target and then activate/deactivate the necessary input/output modules and/or in-game tools using the game editor. For this case study we considered visual, hearing, mobility and simple cognitive adaptations.

As cognitive impairments are very complex and may require very different adaptations, we just considered two possibilities in order to test the game adaptation system: students with low memory capacity, and students with non-severe reasoning problems. In the first case we defined alternative conversations that lessened the amount of information that the student gathers at any moment, thus increasing the focus on relevant information and reducing the amount of "superfluous" information. In the second case we defined alternative game paths with simpler riddles and *puzzles*. Besides, the original *1492* game included an in-game multiple-choice examination at the end of the game through a conversation between the main character (a student called Cristobalín) and his teacher. For both types of cognitive impairments, we provided an alternative, less difficult exam.

In order to cover the rest of potential special requirements, the game is distributed with all of the input/output modules and the screen magnifier. For this to work, we also had to provide alternative descriptions of the visual elements found in each scene, so that they could be passed to the speech synthesizer. This increased attention to descriptions brings the game closer to interactive story-telling games, which often do not have graphical interfaces but intense narrations that engage players.

Finally we produced the rules that adapt the game when the student profile (which is received in the game as input) requests any of the adaptations discussed above. In this case the most difficult task is to define the adaptation rules related to cognitive impairments. This is an issue that is closely related to the game's semantics and flow, so it cannot be abstracted easily. This was achieved by providing alternative versions of several elements in the game (original and adapted conversations, original and adapted puzzles, and original and adapted exams) that are enabled or disabled when the corresponding adaptation rules are triggered.

The resulting game serves as the prototype of an accessible game, and its development helped us to assess the potential and limitations of the accessibility features offered by <e-Adventure>. The most important result is that adding accessibility features that covered a wide range of potential impairments required very little effort and no programming at all. The platform facilitated the creation of a fully-captioned game, where every action can be triggered through a voice command and where feedback can be delivered through a speech synthesizer. The adaptation system allows the creation of a single game that can be played with different levels of cognitive difficulty, including fine-grained adaptations that can be controlled separately, giving the author great control over which sections are modified.

6. CONCLUSIONS AND FUTURE WORK

The current trend in learning technologies towards increasingly complex multimedia and interactive contents presents a significant accessibility challenge. Even though there is an ongoing effort to reduce accessibility barriers in information systems, some of the most innovative media (such as complex interactive multimedia contents or educational videogames) are not receiving enough attention. Entertainment driven games can afford to ignore accessibility concerns, but educational games should be inclusive and available to everyone regardless of their individual conditions.

Nevertheless, the development of accessible games comes at a cost. In educational settings, with limited budgets and markets, the problem becomes greater. In addition, accessible videogames are a relatively new idea, and the existing research in the field is still young and isolated. In this work we have presented the foundations of our approach to accessible educational gaming, which proposes a general framework for accessible videogames and provides a tool to facilitate the inclusion of those accessibility features in educational videogames.

However, the system is still in the prototype stage, and the quality of the results depends on the effectiveness of the supporting technologies. For example, <e-Adventure> is supported by different opensource tools (FreeTTS, Sphinx, Stanford Parser), and the quality of the results is highly dependent on their strengths and weaknesses. Fortunately, these supporting tools are evolving rapidly, and their improvement will bring benefits to the accessibility of any kind of content.

At this stage, our future lines of work will focus on facilitating the process of inputting and maintaining the data from the user model and the context. An interesting approach would be to detect when a student is being challenged excessively by the game or if the student repeatedly fails to react to some outputs from the game, and then load the adaptation features required to compensate those problems.

Finally, our next research will also include coping with cognitive impairments more explicitly. It is an important issue which is rarely covered in the development of accessible IT systems due to its high complexity. Although the effects of ignoring cognitive impairments in entertainment-driven developments might be affordable, they cannot be left aside in educational settings where all the students need to achieve the learning goals. Moreover dealing with cognitive impairments in videogames is interesting as it could improve significantly the learning outcomes of students with such needs, given the close relation between cognition and learning.

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