Journal of King Saud University – Computer and Information Sciences (2014) 26, 29–45

King Saud University

Journal of King Saud University – Computer and Information Sciences

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ORIGINAL ARTICLE

Learning technologies for people with disabilities

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Available online 22 October 2013

KEYWORDS

e-Learning;
Accessibility;
AccessForAll;
Adaptation;
Moodle^{Acc+}

Abstract Nowadays learning technologies transformed educational systems with impressive progress of Information and Communication Technologies (ICT). Furthermore, when these technologies are available, affordable and accessible, they represent more than a transformation for people with disabilities. They represent real opportunities with access to an inclusive education and help to overcome the obstacles they met in classical educational systems. In this paper, we will cover basic concepts of e-accessibility, universal design and assistive technologies, with a special focus on accessible e-learning systems. Then, we will present recent research works conducted in our research Laboratory LaTICE toward the development of an accessible online learning environment for persons with disabilities from the design and specification step to the implementation. We will present, in particular, the accessible version "Moodle^{Acc+}" of the well known e-learning platform Moodle as well as new elaborated generic models and a range of tools for authoring and evaluating accessible educational content.

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1. Introduction

The world report on disability affirms that over one billion people in the world live with some disabilities and there are about 150 million school-aged children with disabilities. Many of these children are excluded from educational opportunities and do not complete primary education. At the same line, recent UNESCO Global report (UNESCO Global Report, 2013) indicates that people with disabilities face a wide range of barriers, including access to information, education and a lack of job opportunities. However Information and Communication Technologies (ICT) can be a powerful tool in supporting education and inclusion for persons with disabilities. Technological development can enable people with disabilities to improve their quality of life (Arrigo, 2005). The successful application of such technologies can make classrooms more inclusive, physical environments more accessible, teaching and learning content and techniques more in tune with learners' needs (UNESCO Global Report, 2013).

In fact, the continuous progress of ICT raised the need to move toward improving the learning quality applied in education and training systems by addressing new perspectives and opportunities. e-Learning emerges as the answer to fulfill that need (Ben Brahim et al., 2013) and vouches to attend the

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Peer review under responsibility of King Saud University.

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http://dx.doi.org/10.1016/j.jksuci.2013.10.005

learning needs of the students in a personalized and inclusive way. Actually, there is no shortage of optimism about the potential of e-Learning to reduce barriers to education and improve the lives of individuals with disabilities (Klomp, 2004). Therefore, developing accessible online educational environments appears as a principal solution to address this issue and to remove the barriers that people with disabilities may meet when they access these learning technologies. An appropriate technology has to provide people with disabilities with adaptive and personalized learning experiences that are tailored to their particular educational needs and personal characteristics. It should also improve their satisfaction, learning speed and learning effectiveness.

In this paper, we propose a conceptual abstract view of an accessible learning environment and we describe a new process allowing the translation of a conceptual model into a specific code adapted to the user's individual learning context. The translation process corresponds to a personalization process which supports people with disabilities learning by accommodating and adapting the learning process to their needs.

In this context, many researchers developed specific tools dealing with specific needs for people with disabilities (Seale and Cooper, 2010; Jemni and Elghoul, 2007; Elghoul and Jemni 2009). However, these tools do not allow the user to adapt the contents to other needs. In fact, when we want to update, we have to modify existing codes. The new codes can be validated only by tests which make it difficult to guarantee the soundness of the result and the preservation of previous properties. For these reasons, we should consider accessibility from an early stage of the systems lifecycle by giving generic models which could be considered as a reference for the following steps of development. By this way, any tool is an instance of such a model and any modification could give an updated content generated by this generic model as a new instance which refines the previous one.

This paper starts by introducing the scope of our work. Section 2 reviews the state of the art related to accessible e-Learning with a special focus on e-accessibility and its related initiatives. Then, in Section 3, we describe our approach covering the different steps carried out to build an accessible e-Learning environment starting from the abstract model and reaching the code generation and evaluation phase. We will also underline the particularity of the accessibility evaluation process we conducted within the e-Learning environment. This section ends through presenting our accessible e-Learning environment Moodle^{Acc+}. The paper is concluded in Section 4.

2. Background

In this section we give an overview of the need of accessibility for people with disabilities. We focus on web accessibility and assistive technologies which offer new designs and tools satisfying the requirements of people with disabilities. Then we present basic concepts of accessible e-learning and its state of the art.

2.1. e-Accessibility

2.1.1. People with disabilities

Disabilities can be grouped according to the type of impairment; generally there are four groups (Kavcic, 2005):

- Mobility impairments (restricted movement or control of arms, hands and fingers): refer to physical disabilities that affect the ability to move, to manipulate objects, and to interact with the physical world
- Visual impairments (blindness, partial sight and color blindness): include the range from low vision to full blindness, where the user cannot use the visual display at all. Although people with visual impairments have the greatest problem with information displayed on the screen (especially graphics and pictorial information), the use of a pointing device, which requires eye-hand coordination (such a mouse), may also pose an issue for them.
- Hearing impairments (deafness and hearing loss): have difficulties detecting sounds or distinguishing auditory information from the background noise. Deaf individuals cannot receive any auditory information at all. Many of them communicate through the Sign Language that differs significantly from the spoken language. Cognitive impairments (including cognitive, language and learning disabilities like attention deficit disorder, dyslexia, dementia, etc.): there are a wide range of cognitive impairments, including impairments of thinking, memory, language, learning and perception.

2.1.2. Assistive technologies

Assistive or enabling technology includes devices, tools, hardware, or software, which enable, partially, people with disabilities to use the computer. It presents an alternative way to access the content on screen, command the computer or process data. Specific adjustment software or devices for manipulating the computer include (Arrigo, 2005).

- Screen reading software (speaks displayed text and allows simulating mouse actions with the keyboard),
- Screen magnification software (for enlarging the content of the screen),
- Braille display (for displaying Braille characters),
- Alternate input devices (e. g. Screen keyboard) and special keyboard (to make data entry easier),
- Keyboard enhancements and accelerators (like StickKeys, Mousekeys, repeatKeys, SlowKeys, BounceKeys, or ToggleKeys), mnemonics and shortcut keys,
- Alternative pointing devices (e. g. Foot operated mice, head mounted pointing device, or eye tracking systems),

These aiding technologies can be either devices or equipments (hardware) e.g. Braille, or software applications e.g. screen reading software. However, these technologies do not seem sufficient for providing full support to people with disabilities. Web content providers should also participate in the inclusion process by making arrangements that allow particularities of people with disabilities to be taken into account when creating web content. Several efforts were conducted toward addressing this issue.

2.1.3. The Web Accessibility Initiative (WAI)

Being conscious of the constraints witnessed by people with disabilities in everyday life especially with web based applications, the W3C carried out a key solution promoting people with disabilities in accessing, using and interacting with the web through the Web Accessibility Initiative (WAI).

The WAI develops strategies, guidelines, and resources to make the web accessible to people with disabilities (W3C Web Accessibility Initiative, 2013).

The WAI targets, among others, web content through Web Content Accessibility Guidelines (WCAG) (Web Content Accessibility Guidelines, 2013), authoring tools through Authoring Tools Accessibility Guidelines (ATAG) (Authoring Tools Accessibility Guidelines, 2013) and user agent through User Agent Accessibility Guidelines (UAAG) (User Agent Accessibility Guidelines, 2013).

In the WAI model, the WCAG is complemented by accessibility guidelines for browsing and access technologies (UAAG) and for tools to support creation of Web content (ATAG) (Sloan et al., 2006).

These guidelines are mainly based on the following four criteria:

- Perceivable – information and user interface components must be presentable to users in ways they can perceive,
- Operable – user interface components and navigation must be operable,
- Understandable – information and the operation of user interface must be understandable,
- Robust – content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies (Laabidi and Jemni, 2009).

The WAI was widely deployed in various web application areas aiming to include the left out user groups. In fact, this inclusion became an acquired right for the people suffering from disabilities in different countries. Since education is one of the major concerns of ICT, applying WAI in this domain is very promising.

2.2. Accessibility in e-learning

Involving accessibility in e-Learning aims to ensure that the opportunities offered by the e-Learning paradigm are guaranteed to everyone, including people with disabilities.

Asserting that, Sampson and Zervas (2011) describe the issue of accessibility in relation to technology-enhanced training by ensuring that learners are not prevented from accessing technology-supported resources, services, and experiences in general due to their disability.

Therefore, acknowledging accessibility in e-Learning is a key issue vouching to promote and ensure e-inclusion of students with disabilities. Furthermore, it bares the potential to eradicate barriers witnessed by students with disabilities in accessing on-line digital resources.

In the same scope, Perry (2004) sustains that making e-Learning accessible ensures that resources can be used by all learners regardless of environmental or technological constraints, and allows individual learning styles and preferences to be accommodated.

2.2.1. IMS Global Learning Consortium specifications

The IMS Global Learning Consortium developed various specifications and guidelines focused on adaptation or personalization of resources, interfaces and content to meet the needs of individuals (IMS Global Learning Consortium, 2001). Among these specifications, the IMS Access For All is designed to define and describe resource accessibility. Its goal is to provide a means whereby resources are matched to the individual accessibility needs and preferences of a particular person (IMS Global Learning Consortium, 2013).

The IMS Access For All specification enfolds two elements: IMS Accessibility Metadata Description (ACCMD) (IMS Global Learning Consortium (2013) handling the description of the learning resource and IMS Accessible Learner Information Package (ACCLIP) (IMS Global Learning Consortium, 2013) ensuring the description of learner's preferences.

2.2.1.1. IMS accessibility metadata description. One side of the match is the description of the learning resource. An important addition to the metadata standards is Accessibility Metadata. Accessibility Metadata elements provide information about the resource such as the senses needed to process the resource, the ability of content to transform in ways necessary for accessibility and the availability of equivalent resources (Treviranus and Roberts, 2008).

Accessibility Metadata divides learning resources into two categories: (1) Primary resources and (2) equivalent alternatives (Fig. 1)

(1) Primary resource refers to the original resource created by the author. The metadata that is collected for these resources is kept to a minimum to reduce the workload on the author (Treviranus and Roberts, 2008).

Information collected includes the following:

- A statement about the flexibility of the presentation and control of the resource.
- A statement about the mode of access that indicates whether vision, hearing, text literacy or touch is required to use the resource.
- A URL for any known equivalent alternative such as a caption file for a video resource. Equivalent or alternative resources replace or supplement primary resources to address an accessibility issue that a learner may have with the primary resource.

(2) Equivalent alternatives: equivalent or alternative resources communicate the same learning objective or lesson as the primary resource, but do so in another modality that is accessible to the learner.

Through accessibility metadata, resources that are accessible or can be made accessible are easily identified and utilized by educators, learners or the learning management system they employ (Treviranus and Roberts, 2008).

2.2.1.2. IMS Accessible Learner Information Package. The other side of the match is learner needs and preferences. Through ACCLIP, the learner can express preferences for

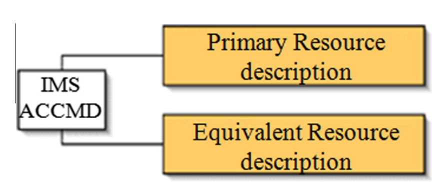

Figure 1 IMS ACCMD Components.

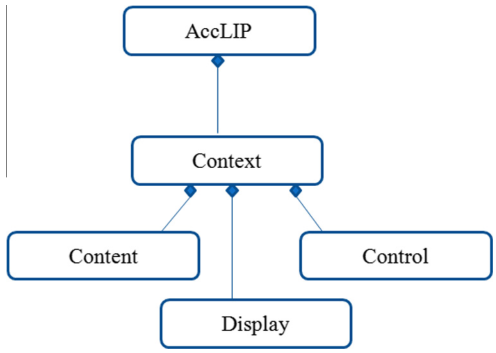

Figure 2 IMS ACCLIP components.

how the resource should be displayed, how the resource should be controlled and what form of content should be delivered. These preferences can be applied to both the standard system and available assistive technologies. An important approach of the ACCLIP specification is that it is not disability-centric.

Instead of assuming preferences based on stated disability, the ACCLIP specification assumes that any learner will have different access preferences depending on any number of factors: their location, bandwidth, access device and subject of study to name a few. Access For All is about individualization and customization for the learner in a way that benefits all learners.

ACCLIP is the corresponding specification or match to accessibility metadata: a learner is able to specify accessibility preferences like text alternatives to image content, and the appropriate resource that meets these preferences can be identified by the corresponding accessibility metadata (Treviranus and Roberts, 2008).

Accessibility preferences are grouped into three categories: those related to content, those related to the content display and those related to the control of the content as illustrated in the Fig. 2.

2.3. IMS/ISO specification

More recently, a new standard has emerged into the accessibility scene: the ISO FDIS 24751 Accessibility standards (ISO/IEC 24751 Information Technology, 2008). As the IMS Access for All specification, the ISO specification is based on the learners' profiling and on the description of the didactical materials through metadata (Mirri et al., 2009) as described in the Fig. 3.

The framework is divided into the following concepts, which, when used in conjunction, make possible the matching of digital educational resources with the needs of individual users:

- A statement of the needs and preferences of the individual user, at the time and in the context they are in 2000 (Access For All personal needs and preferences profile – PNP): (IMS Access For All Personal Needs and Preferences Description for Digital Delivery Information Model, 2013). It defines three elements, as shown in Fig. 4, being:
  - "Display": defines how the interface and content should be presented to the learner. It covers speech synthesizers (e.g. screen readers), screen enhancement (e.g. screen magnifiers), text highlighting, Braille settings, tactile displays, visual alternatives to audio alerts, and content structure.

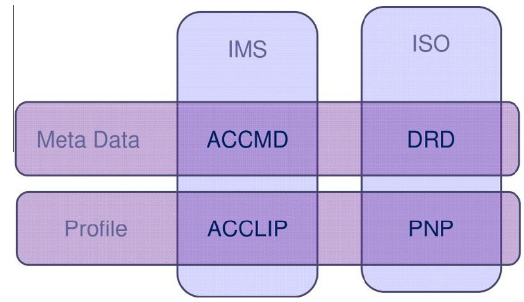

Figure 3 The IMS/ISO specifications.

  - "Control": defines alternative ways of controlling the technology. It covers accessibility enhancements for a standard keyboard, virtual keyboards, alternative keyboards, mouse emulators, alternative pointing devices, voice recognition settings, and navigation through content.
  - "Content": defines content preferences, such as alternatives to visual content (e.g. audio descriptions), alternatives to text (e.g. graphics), alternatives to audio content (e.g. captions), links to personal style sheets and requests for extra time (Perry, 2004).
  - A statement of the relevant characteristics of a resource to be matched to the PNP (Access For All digital resource description DRD) which assumes two categories of resources: original and adapted (Fig. 5). An original resource is the initial or default resource. An adaptation contains the same intellectual content as an original resource but in a different form such as in a different sensory mode, or with more or less dense semantics 2009(The IMS Global Learning Consortium, 2013).

Through its Accessibility Project and the specifications it provided, IMS added a major value to the people with disabilities' integration in online education. Several works deployed the Access For All specification such as the two tools ATutor and TILE.

ATutor includes a variety of features designed to ensure that content is accessible to all potential users, including those with slow Internet connections, older Web browsers, and people with disabilities using assistive technologies to access the Web (ATutor learning management system, 2003). ATutor uses the TinyMCE HTML editor, which is accessible to a broad range of browser and assistive technologies, and which prompts content authors to produce accessible content. Many of the accessibility features in ATutor are based on the Web Content Accessibility Guidelines developed by the W3C and a consortium of groups around the world.

The Inclusive Learning Exchange (TILE) is a learning object repository service that responds to the individual needs of the learner. It provides the authoring tools, repository architecture, and preference schema needed to support this learner-centric transformation (The Inclusive Learning Exchange (TILE), 2004). Based on ACCLIP, TILE allows the user to customize the presentation of content to suit his own needs.

As described above, all accessibility solutions are based on WAI and the Access For All specifications. They deal with one problem at the time: content or presentation. Furthermore all these solutions are ad hoc implemented and they do not take into consideration the technology evolution. In the next

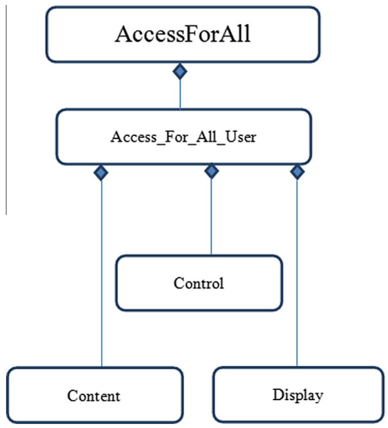

Figure 4 AccPNP components.

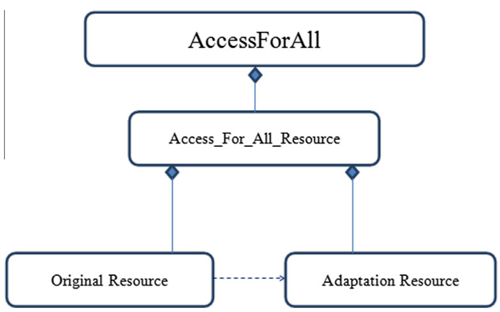

Figure 5 AccDRD components.

section, we will present our approach to build an accessible e-learning environment covering all its steps, starting from the design to the implementation.

3. Our approach to build an accessible e-Learning environment

Most available e-learning systems for learners with disabilities are limited to deliver accessible learning contents. However, the learners with disabilities need the whole accessible TEL environment and not only the accessible content. In fact, providing accessible content in a non accessible learning environment leads to a non accessible learning experience. In the following, we present the main limits of the available systems.

- Some of these systems are limited in a particular environment so the posterior applications cannot profit from the valuable experiences gained through local use and consequently cannot be easily identified and adopted by larger communities of educational practitioners and training organizations (Sampson and Zervas, 2011).
- Many of them are typically based on accessible learning content that is designed and only recognizes the specific accessibility requirements of a particular user group (Sampson and Zervas, 2011).
- The e-learning environment may contain some non accessible tools that prevent people with disabilities access to the content even though this is in an accessible format.
- Some systems may provide content during the learning process that does not meet the specific needs of each type of disability.
- Some systems use accessible learning resource designed to be accessible to everyone, but not optimal to every user.
- Most systems lack the possibilities of personalization since they give the same contents to all students (Chorfi and Jemni, 2003).

Our approach targets to address these issues and to ensure these objectives:

- Remedy to the lack of environments, taking into account the design of accessible e-Learning applications.
- Lead the learner in specifying his needs and preferences regarding the control as well as the presentation of the learning content he wishes to exploit in the e-Learning environment.
- Ensure that the content embedded in the e-Learning environment is fully exploitable and usable by learners with disabilities.
- Ensure full accessibility of the learning environment in its content, its content presentation as well as its control.
- Adapt learning environment to meet the needs of people with disabilities by personalizing the training process for every user.
- Assert the establishment of the accessible environment for e-Learning by developing and embedding a platform accessibility evaluation tool.

In order to reach these objectives the proposed approach relies on 3 phases namely design, implementation and evaluation as exposed in Fig. 6.

3.1. Design of accessible e-Learning systems

Good design is at the core of inclusive educational technology (Treviranus and Roberts, 2008). Based on this assumption, accessible e-learning refers to design qualities that endeavor to make online learning available to anyone irrespective of their disability, and to ensure that the way it is implemented does not create unnecessary barriers to him/her interacting with a computer or connecting device (Cooper, 2006).

Therefore, accessibility has been recognized as a key design consideration for technology-enhanced training systems ensuring e-inclusion of people with disabilities in the training process and consequently preventing risks of ‘‘digital exclusion’’ (Sampson and Zervas, 2011).

Unlike existent systems, based on an ad hoc accessibility implementation, we are considering accessibility from an early stage of the systems lifecycle. For this reason, adopting the accessibility since the design phases could provide a rational solution to this problem. A generic model could give an abstract view of elaborated systems which could be used as a reference description corresponding to specific tools supporting any update.

We carried out this solution by establishing a conceptual basis that will allow to integrate accessibility in e-Learning systems.

In order to achieve the above mentioned, this section will cover different works conducted in our LaTICE Research Laboratory (Research Laboratory in Technologies of Information and Communication and Electrical Engineering, 2013) to address the design of accessible e-Learning systems.

First, we start by presenting the formalism to model accessibility described in (Laabidi and Jemni, 2009) called Profile Based Accessible E-learning formalism (PBAE). Then, we describe the extension of this formalism by a new UML meta-model in order to model e-Learning accessibility specifications. This meta-model is called ACCUML. ACCUML is based on the IMS Access For All and gives the designer the possibility to represent the keys of accessible e-Learning systems: the presentation and the control.

The basic pillar of these works was the OMG Model Driven Architecture (MDA) which was deployed as it turns out to be most relevant to address accessibility from an early stage in the systems lifecycle.

MDA is an approach based on Model view Systems. MDA separates business and application logic from underlying platform technology [http://www.omg.org/mda]. This approach depends on the definition of:

(1) Specification model called Computational Independent Model or CIM,
(2) Conception model called Platform Independent Model or PIM,
(3) An implementation model called Platform Specific Model or PSM,
(4) A set of model transformations (Laabidi and Jemni, 2010).

We intend to develop a meta-model for accessible e-learning systems which could be used to generate a specific system for specific needs. Every elaborated system corresponds to a model and every model has to be assigned to the same meta-model and not to the other one. This generic meta-model allows adaptation, modification, and flexibility considering different contexts. Those are guaranteed when a semantic link is defined between elaborated systems and the meta-model by the use of a transformation language ATL (ATL, 2006). For that, we need an UML profile considering e-learning aspects combined with accessibility requirements.

3.1.1. The Profile Based Accessible E-learning formalism (PBAE)

This formalism aims to define a modeling language for developing accessible e-Learning systems. The *PBAE* is mainly based on the definition of UML profiles which supports customizing by personalizing UML models for particular domains and platforms (Fuentes-Fernández and Vallecillo-Moreno, 2004).

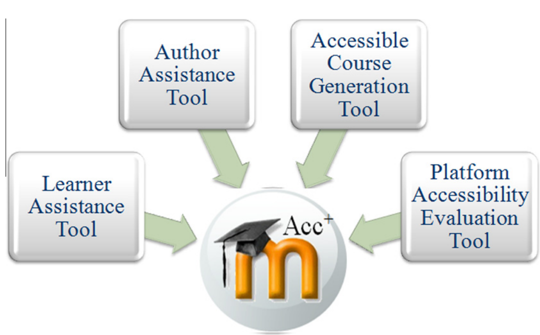

Figure 6 The proposed environment.

The PBAE applies UML profiles in the three levels relative to the MDA approach. This idea is illustrated in Fig. 7.

Fig. 7 describes the PBAE architecture which associates a profile to each level of the MDA approach. It shows that the transfer from one model to another or the refinement of the same model is ensured by a set of transformation rules driven by UML profiles.

3.1.2. The ACCUML meta-model

In the same scope, we have extended PBAE into a new UML meta-model called "*ACCUML*" for the modeling of digital accessibility in e-learning systems. This extension was performed to establish the basic foundations for modeling accessibility. Through the ACCUML meta-model, the UML basic meta-models were enriched in order to support accessible e-Learning systems design.

Fig. 8 shows the proposed meta-model in order to support accessible e-Learning application. The applied extension is given by adding two concepts: the concept of presentation "Display" and the concept of control "Control". The presentation and control concepts were chosen considering their particularities for each type of disability, unlike non-disabled users where the presentation and control are elements of comfort (Figs. 9 and 10). The Use Case Meta-model commonly describes the application specification requirements which will be presented through use cases.

This work is concretized through the development of a new computer based software engineering called ArgoUML^{acc+}. In previous works conducted within LaTICE Research Laboratory (Hebiri et al., 2010; Laabidi and Jemni, 2010; Laabidi and Jemni, 2009), we performed an adaptation of the IMS Access For All accessibility elements, in order to assert a personalized learning experience. We designed accessibility models corresponding to every type of disability by means of the access For All specification in order to develop accessibility models that are specific to each disability type. These models were developed according to the learner's individual

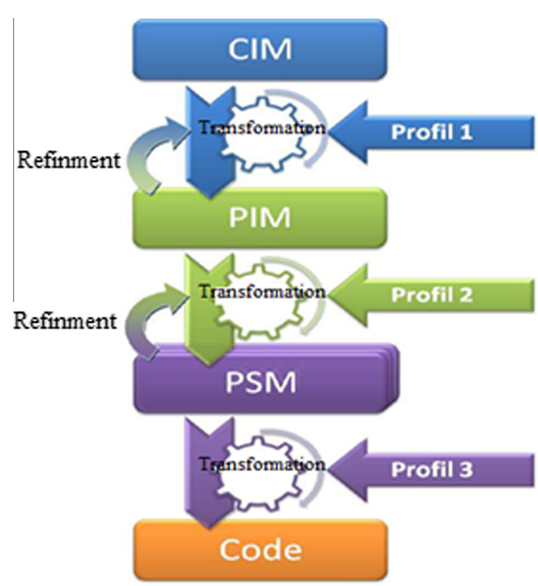

Figure 7 Architecture of PBAE.

preferences and needs in order to match learning content with learner accessibility preferences.

Then, we integrate them within the Computer Aided Software Engineering ArgoUML (Mirri, 2006). The result is ArgoUML^{Acc+} through which we can create Platforms Independent Accessibility Models (PIM). The accessibility models (PIM) consist in the learner's needs and preferences statement personalized to his disability type.

3.2. Implementation of an accessible e-Learning environment

Following the previous step, the integration of the obtained models in the e-Learning systems is needed. This integration requires some transformations depending on the chosen e-Learning platform. This transformation relies on transformation rules which transform the PIM in order to obtain Platforms Specific Models (PSM) (Figs. 11 and 12).

3.2.1. Models transformations

After the elaboration of a platform independent Model (PIM), we generate its correspondent XMI model by transformation. This makes easier the transformation into PSM and also the integration. The following figures show how display and control appear in the XMI code.

3.2.2. Extension of PHP meta-model

To take into account the PHP platform in the MDA approach, we chose the meta-model according to standard PHP MOF presented below. This meta-model defines the structure PHP applications models. The objective of the development of the meta-model was twofold. On one hand, it allows the transformation of models into UML 2.0 component model and PHP. On the other hand, it facilitates the generation of the PHP code. This meta-model is a demonstrator illustrating the feasibility of our approach.

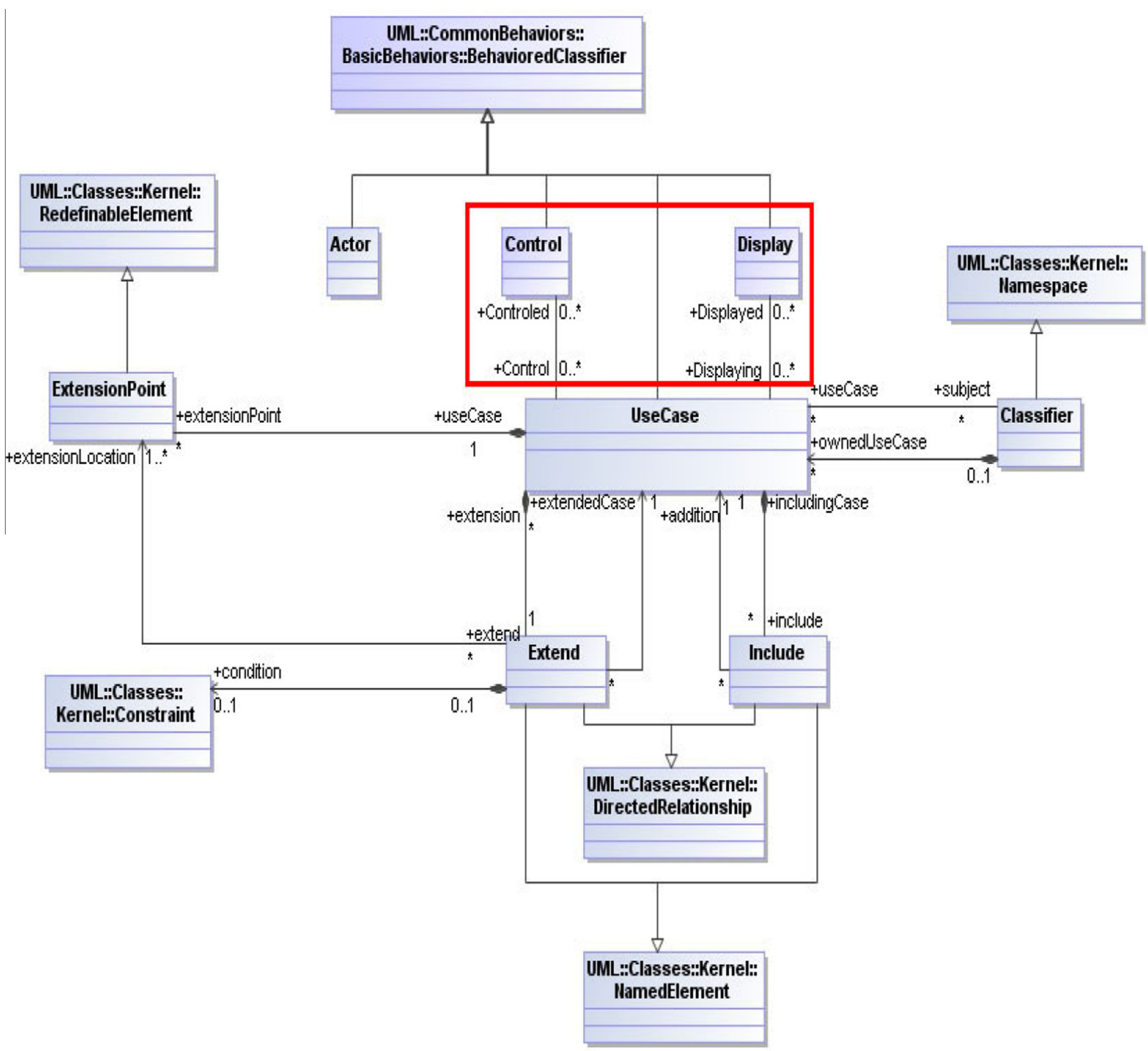

Figure 8 The *ACCUML* Meta-model.

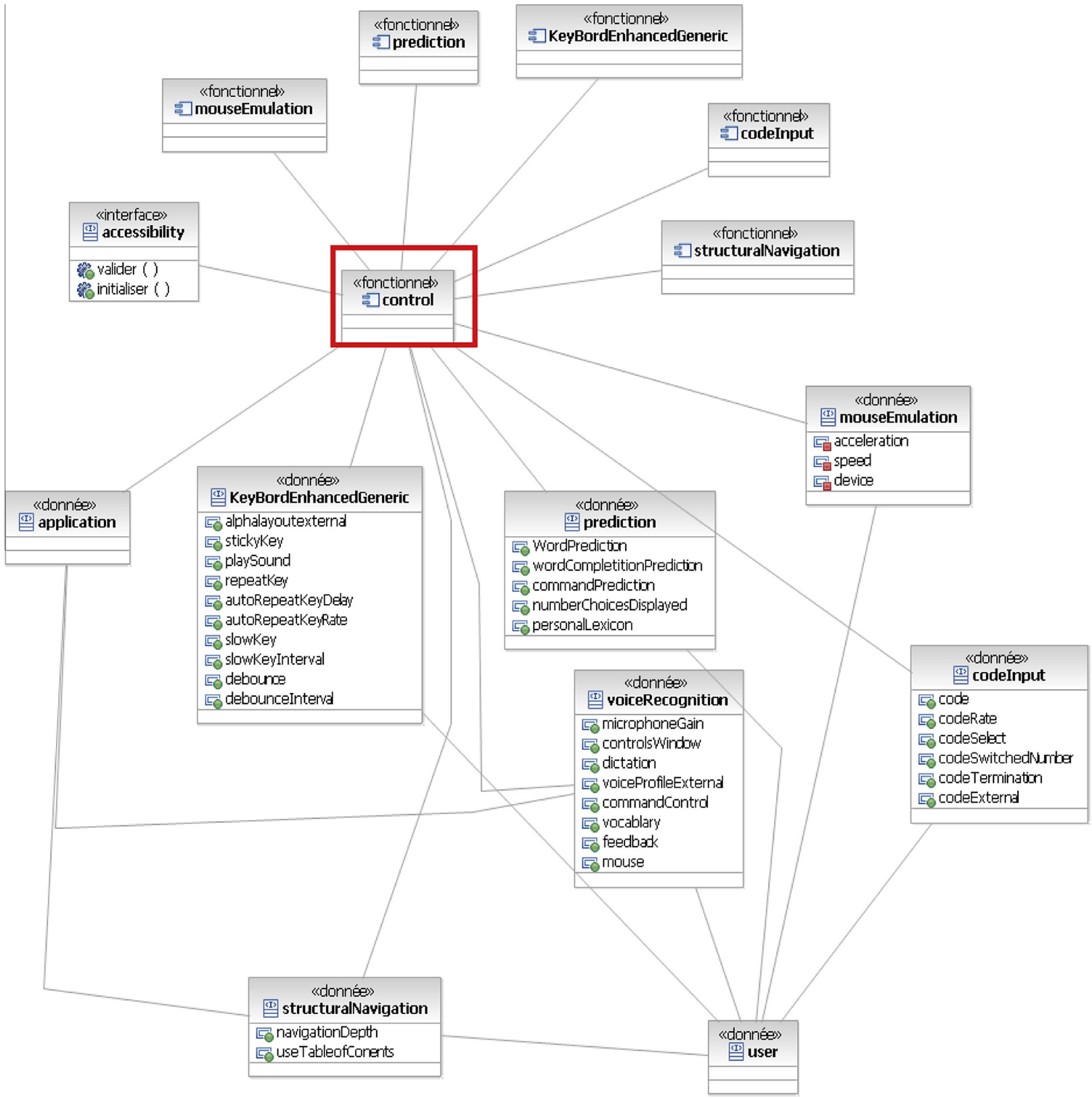

Figure 9 The IMS Accessforall *Control* Model.

To model the inclusion of PHP mechanism, we introduce the concept of resource, which represents any file accessible via a path (Fig. 13).

a. The meta class "Resource", which has a metadata attribute called path.
b. The meta class "Library." This meta class inherits the meta class "Resource".

3.2.3. *Moodle*$^{Acc+}$

To exploit the accessibility models and ensure their effective use to establish an accessible environment for e-Learning, we integrate accessibility models in the open source e-Learning platform Moodle. The result is the new e-Learning environment *Moodle*$^{Acc+}$ that we developed as an accessible version of the platform Moodle.

With the platform *Moodle*$^{Acc+}$ we can use the built-in accessibility models while matching the content with learner preferences to get a personalized learning experience.

Moodle^{Acc+} offers several services to the e-Learning community:

- Learner Assistance Tool,
- Author Assistance Tool,
- Accessible Course Generation Tool,
- Platform Accessibility Evaluation Tool.

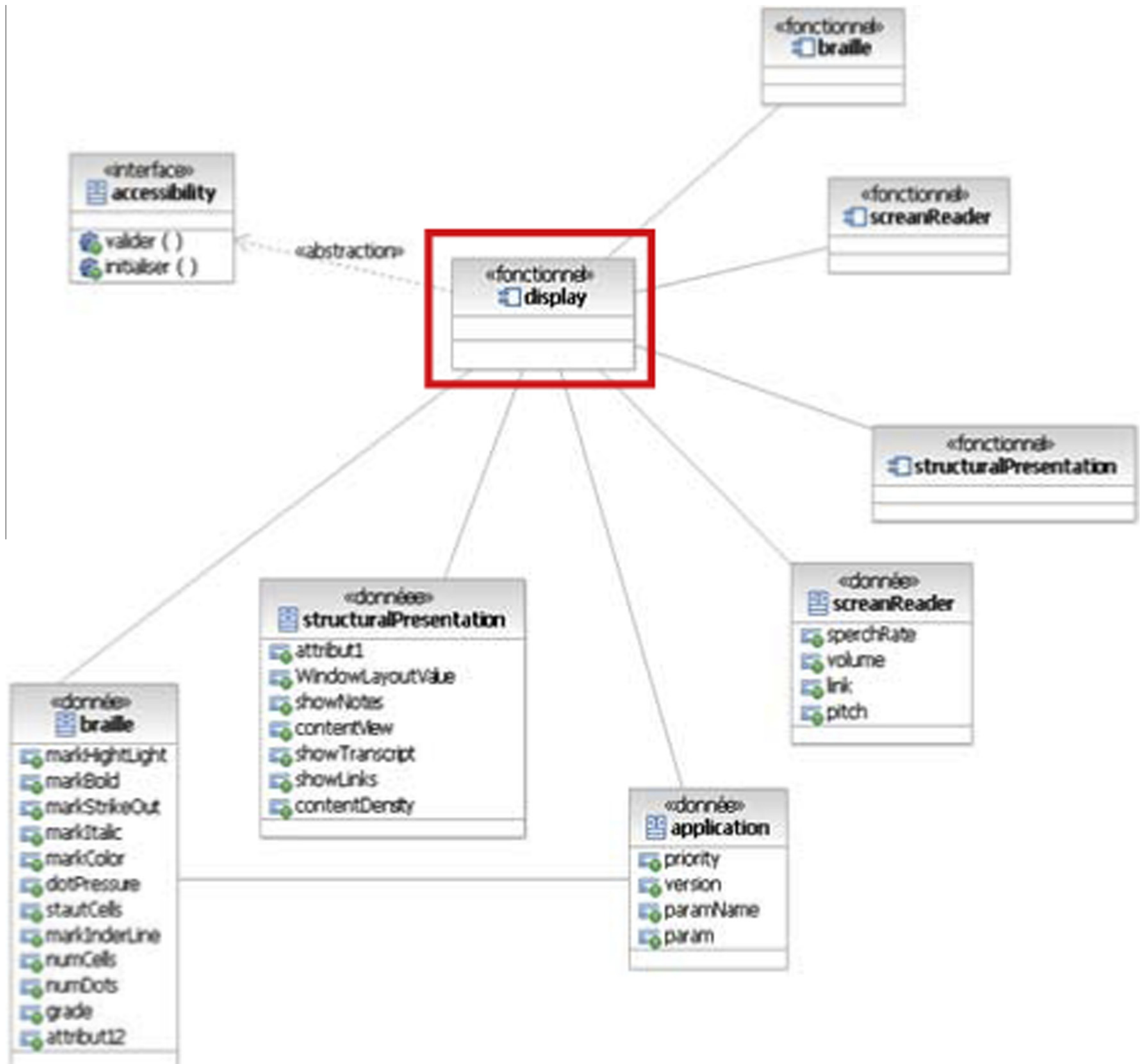

Figure 10 The IMS Accessforall *Display* Model.

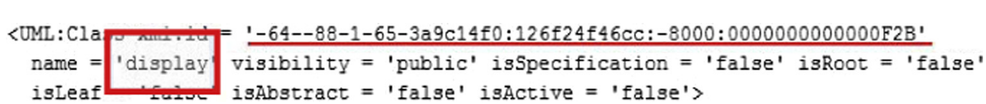

Figure 11 The XMI Display class transformation.

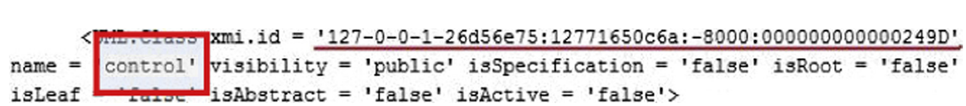

Figure 12 The XMI Control class transformation.

3.2.3.1. Learner assistance tool. Moodle^{Acc+} gives to learners the possibility to specify and edit his preferences through its Learner Assistance Tool. This tool is based on the specific accessibility models we developed and integrated in Moodle. Once the learner specifies his disability type, the relevant model is generated allowing the learner to state his preferences in a personalized way.

Fig. 14 represents a screenshot of the wizard appearing once the learner expresses his will to create his accessibility profile within *Moodle^{Acc+}*. It allows the learner to specify his disability type.

Once the selection is done, the specific accessibility model is generated leading the learner to specify his preferences concerning the content, the display and the control as shown in Fig. 15.

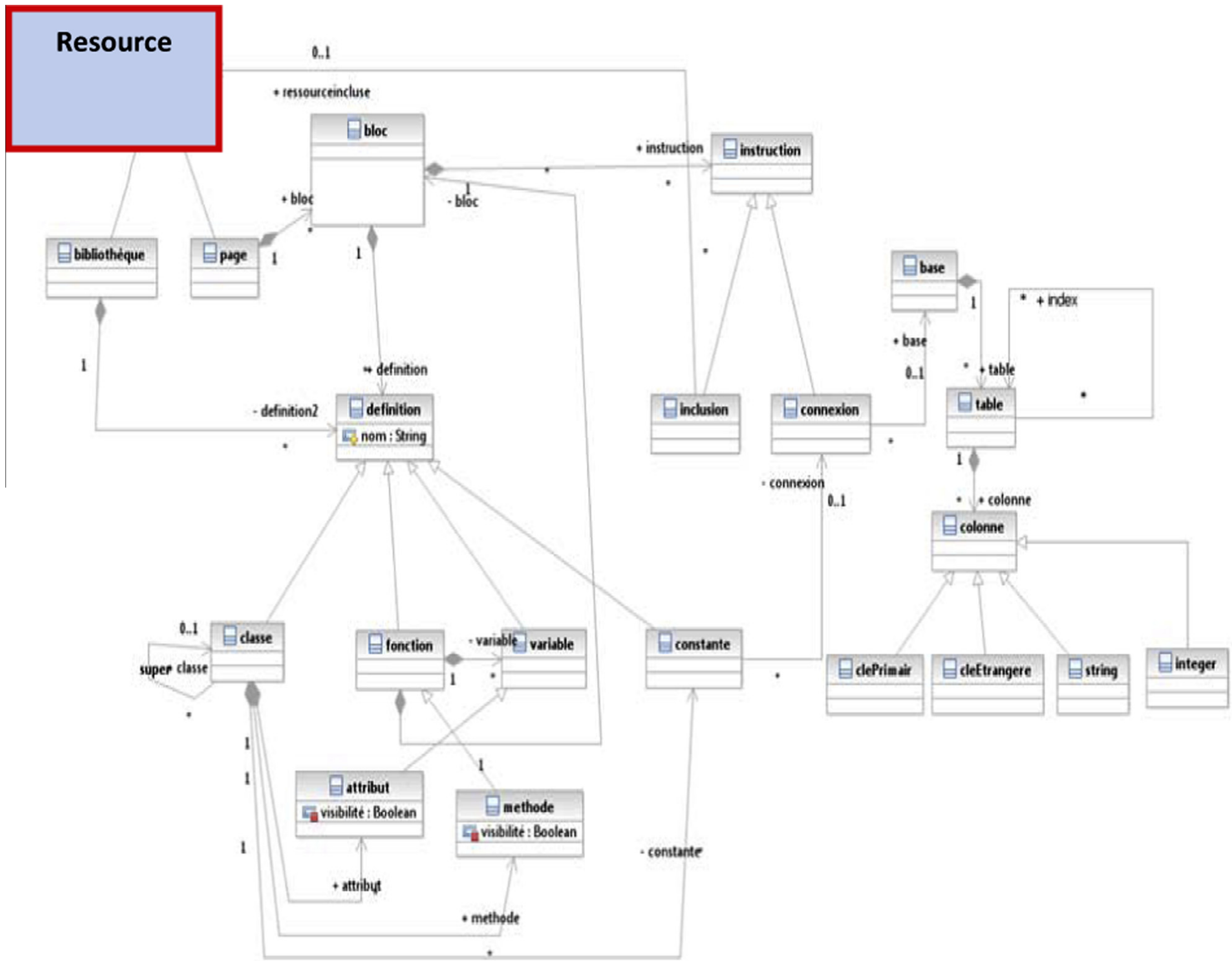

Figure 13 The Extended PHP Meta-model.

3.2.3.2. Accessible course generation tool. Based on these preferences and available contents, our system generates a personalized learning experience conforming to the learner preferences. For instance, a learner is studying a course on the solar system containing a video of the solar system's formation and evolution. A user without a PNP file or with a PNP file, but without expressed needs or preferences concerning audio or visual content, would receive the original video as shown in Fig. 16.

However, another user who has a hearing impairment may require captions. In this case, it would be necessary for the original video to be supplemented by an adaptation. When this user requests to view the course on the Solar System containing the video of the solar system formation and evolution, the system recognizes that the user needs an alternative to the auditory components. It checks the video's adaptations and discovers that an adaptation exists with a caption that matches user requirements. The metadata for the caption file indicates that it is a partial adaptation and should be displayed with the video. The system displays the video with its supplementary captions as shown below in Fig. 17.

Another illustrative example involves a color blind student who requires a course on the neural system. The course is initially presented in its original format including a color image as in Fig. 18.

This user proceeds on creating his PNP file in which he specifies his request asserting that the information will not be transmitted through color. Therefore, the color images will be replaced by gray level images in the generated course. In our example, the generated course is shown in the Fig. 19.

3.2.3.3. Author assistance tool. Moodle^{Acc+} gives the authors the possibility to index the learning resources with accessibility meta-data as well as providing several alternatives through its Author Assistance Tool.

Fig. 20 is a screenshot of the course creation wizard which gives an author willing to create a course the possibility to index the learning resources with accessibility metadata.

Fig. 21 is a screenshot of the accessibility metadata corresponding to the AccDRD specification through which the author specifies if he is willing to give adaptations to the original resource.

The Fig. 22 is a screenshot of the adaptation accessibility metadata. The author can specify adaptations to be provided and index them with the relevant accessibility metadata.

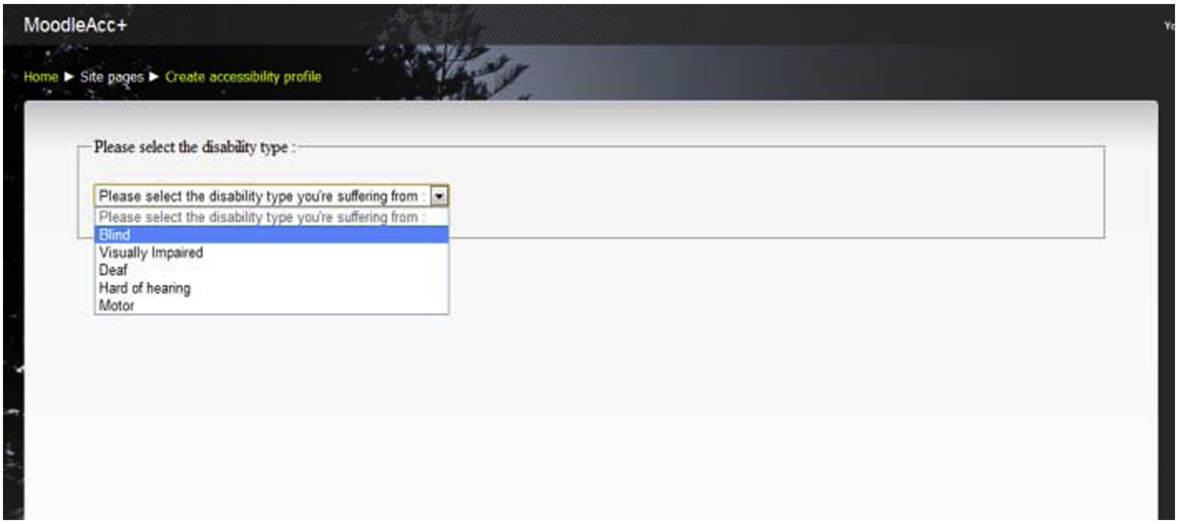

Figure 14 screenshot of the Disability type selection wizard.

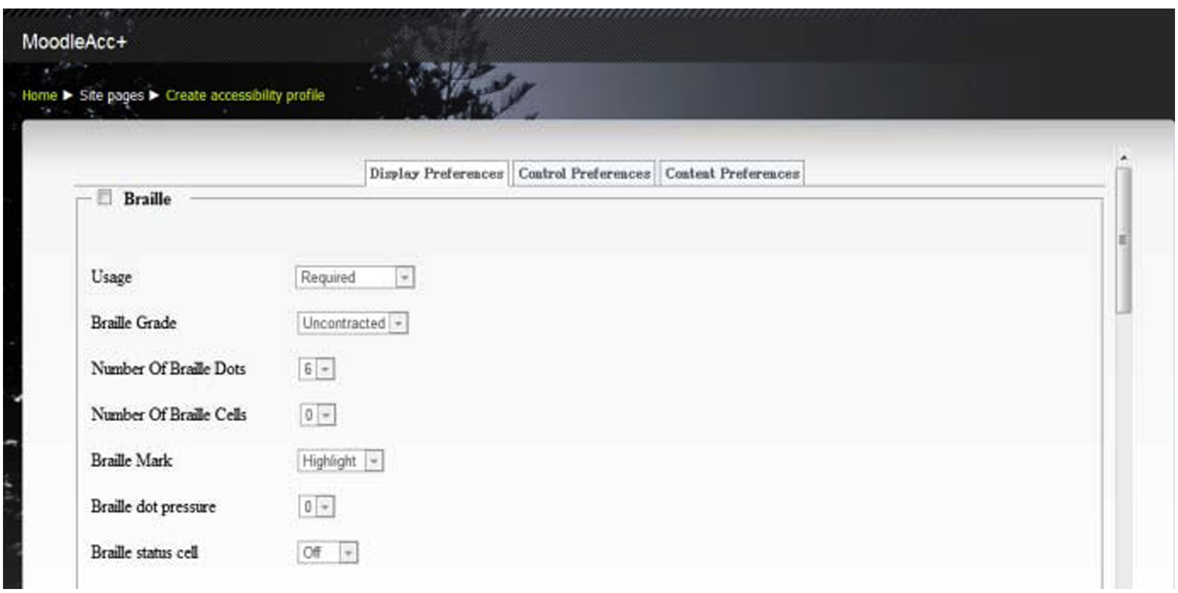

Figure 15 Screenshot of learner's preferences edition.

3.3. Evaluation of accessibility in e-Learning environment

To assess the accessibility of an e-Learning environment, we developed a system to evaluate the accessibility of the e-Learning platform.

To evaluate the accessibility we investigate how the needs of learners with disabilities are considered in the e-Learning environment, in particular, the way the learner can exploit the content as well as the way the learner can get the content. The evaluation module is integrated and applied in $Moodle^{Acc+}$.

3.3.1. Platform accessibility evaluation

Accessibility evaluation is based on tools which are software programs or online services that decide if web content meets accessibility guidelines. However, even though the web content might be accessible, it does not mean that it is profitable and exploitable by people with disabilities. Yet accessibility evaluation tools are restricted to web content. Therefore, the need is to focus on evaluating the learning content as well as the e-Learning environment embedding and delivering this content.

The platform accessibility evaluation targets the enhancement of e-Learning platforms regarding their accessibility considerations. To evaluate the accessibility, we analyzed how the environment addresses the needs of the learner in control and display, otherwise:

- How the learner can use the content?
- How the content is going to be represented?

The evaluation is based on a validation of the Schematron documents. The Shematron is an ISO standard consisting in a language for making assertions about the presence or ab-

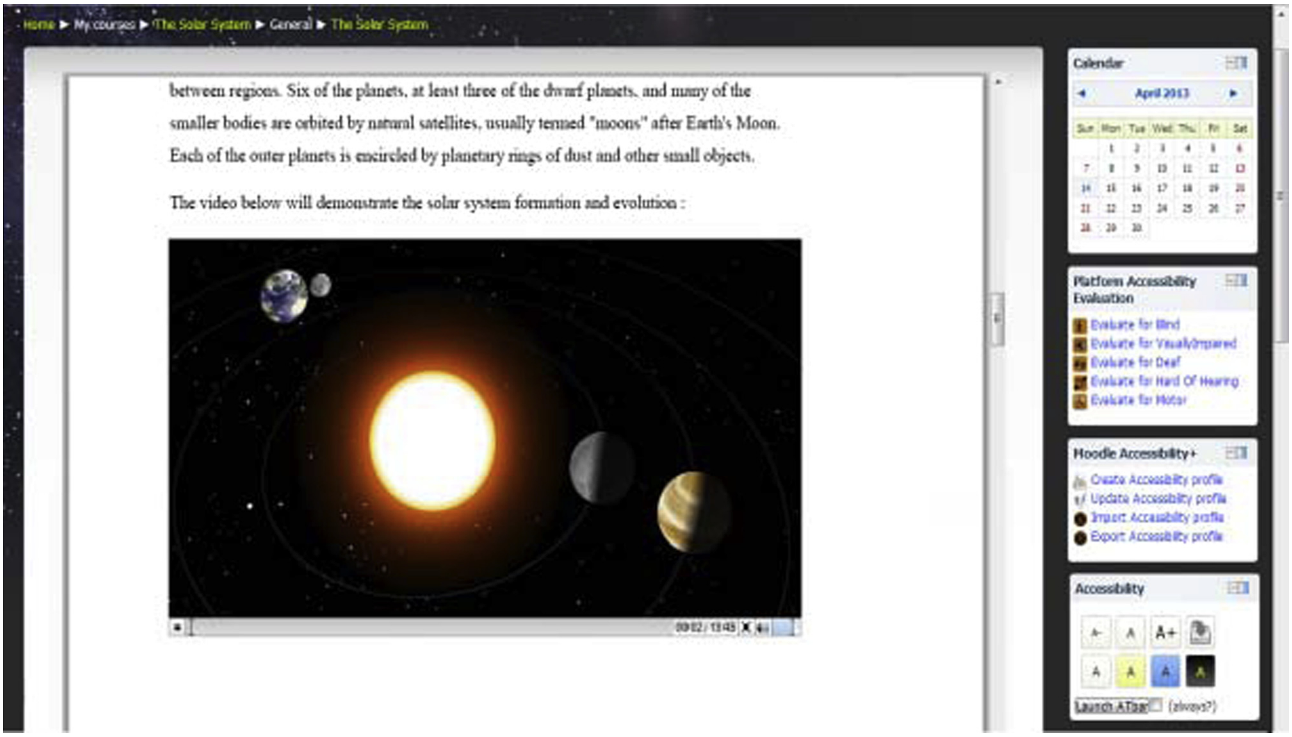

Figure 16 Screenshot of the solar system course video without captions.

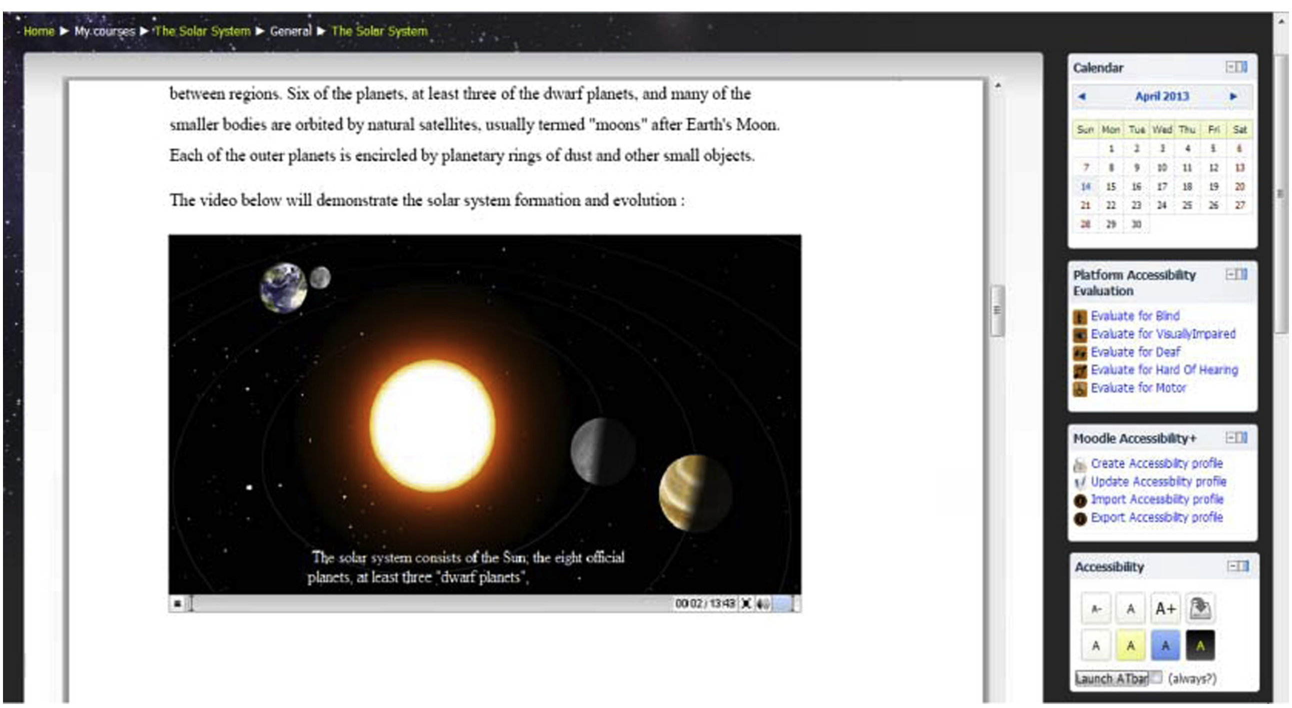

Figure 17 Screenshot of the solar system course video with caption.

sence of patterns in XML documents 2006(ISO/IEC Schematron, 2013). For each learning object (content), we evaluate its control and display using validation based on XML Shematron documents. For each disability type, we perform a diagnosis of the platform by parsing the corresponding display and control Schematron files testing if the learning resource (content) meets the user preferences in control and display.

To properly perform the evaluation we need to create in advance, based on the accessibility specific models already elaborated, the Schematron files containing the display, control elements from the AccPNP specific model and the content

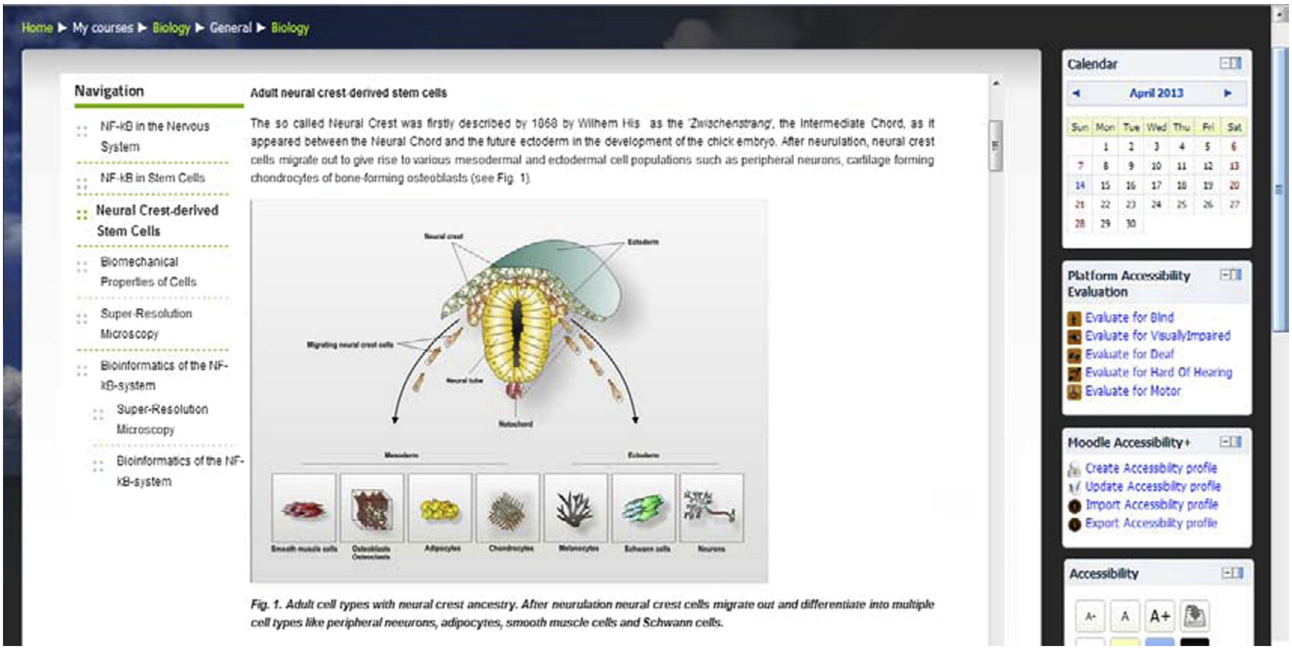

Figure 18 Screenshot of the neural system course with a colored image.

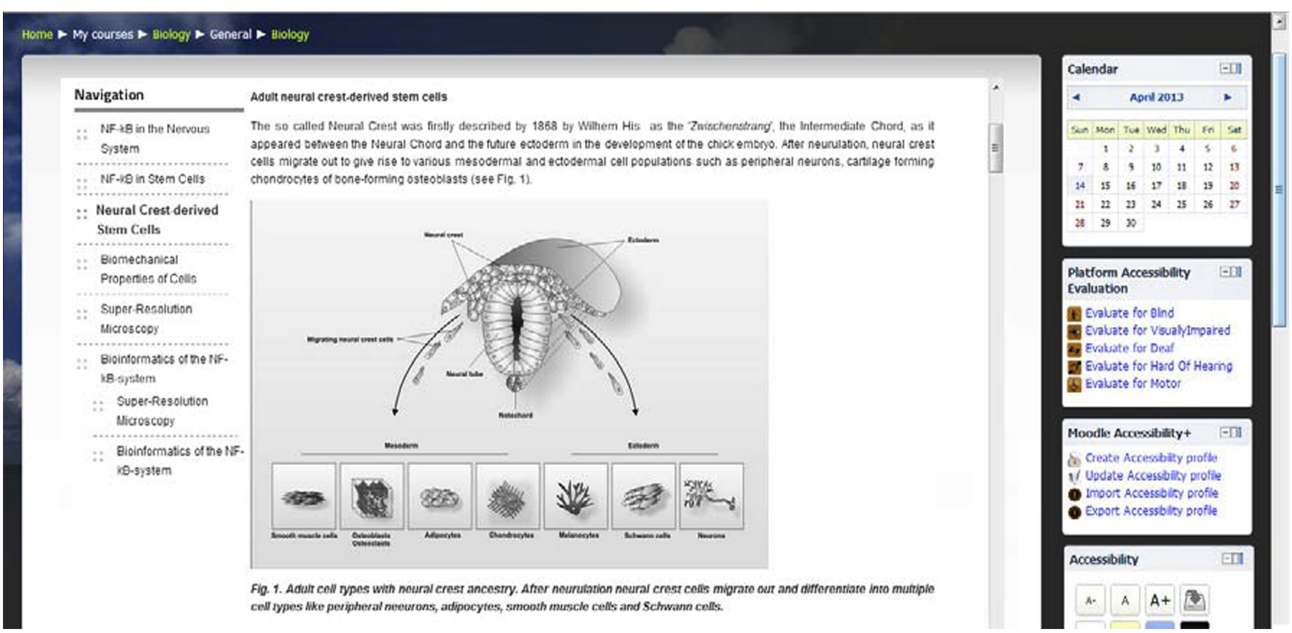

Figure 19 Screenshot of the neural system course with a level gray image.

elements from the AccDRD specific model. Therefore, the evaluation follows the following steps:

- Extraction from the Data Base of the accessibility metadata corresponding to the learning resource required by the learner.
- Creation of the corresponding XML files structuring the accessibility metadata extracted from the DB.
- Validation of the XML files with the Shematron files already created based on the accessibility specific models.

Finally, a report is generated detailing the accessibility flaws in the e-Learning platform in an easy and readable format.

3.3.2. *Moodle^{Acc+} platform accessibility evaluation tool*

This tool enables authors and tutors to evaluate the accessibility of a course within the given learning environment. Through selecting a course, an author or a tutor can be aware of the accessibility problems that exist in the course within the given learning environment. Furthermore, this

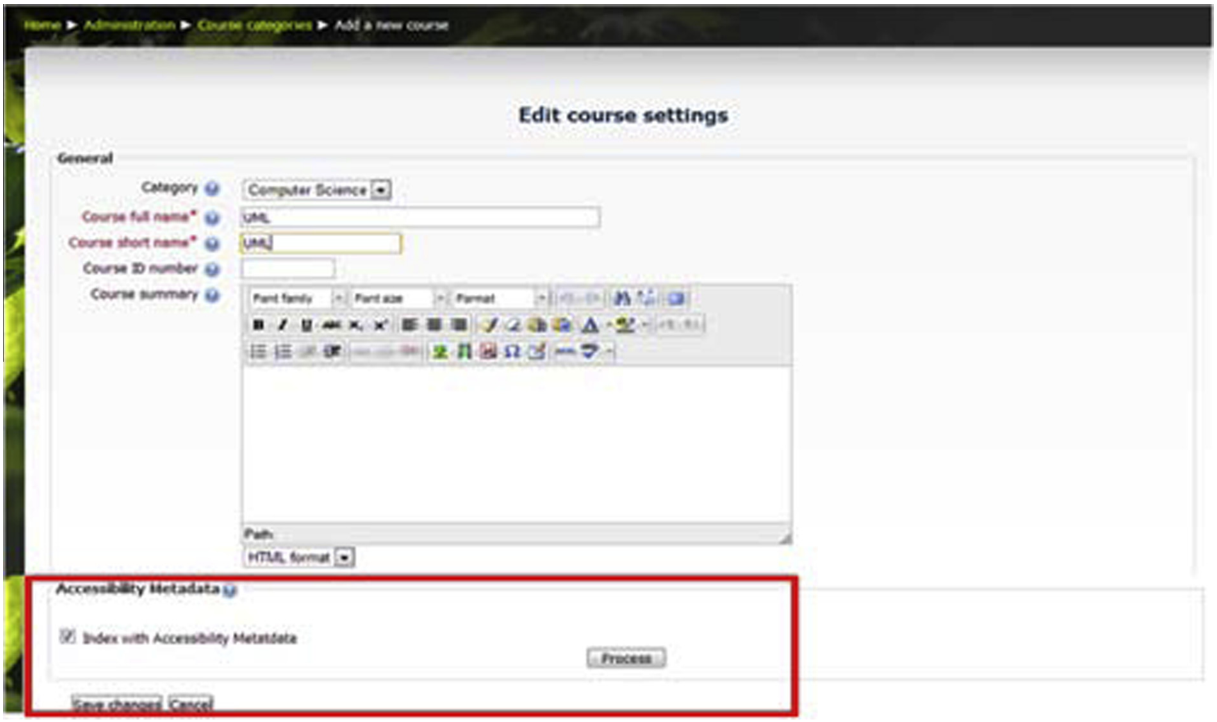

Figure 20 Screenshot of the course creation wizard.

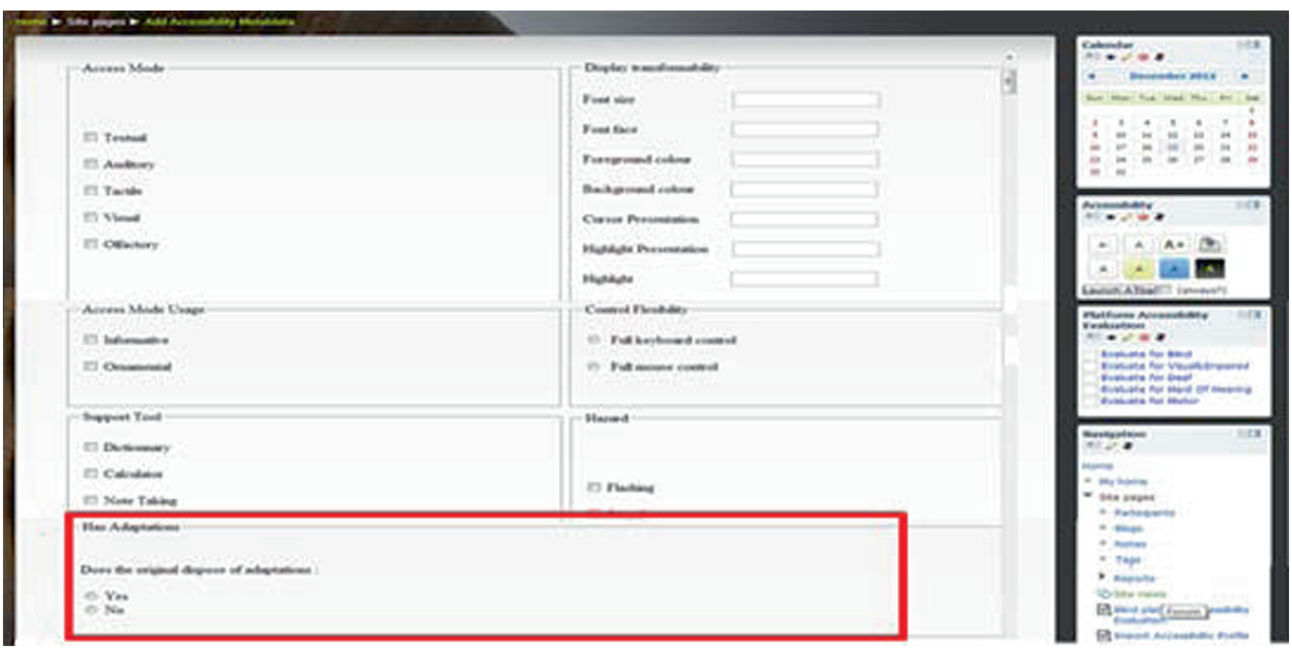

Figure 21 Screenshot of AccDRD Accessibility Metadata.

tool offers a personalized evaluation since the targeted user can choose from the beginning which disability type the evaluation to be performed concerns. Fig. 23 shows a screenshot where the tutor is selecting a course to evaluate its accessibility for Blind disability within *Moodle*$^{Acc+}$ learning platform.

The evaluation diagnosed accessibility flaws regarding content, display and control. The report is provided in a table format whose last column concerns a message about the correction to be performed to remedy each flaw.

Fig. 24 shows the wizard through which the user can view the evaluation reports already performed and saved in the data base.

4. Conclusion

In this paper we proposed a new approach for the development of accessible e-Learning environments. It consists of three phases: design, implementation and validation. The approach has been applied over the e-Learning platform Moodle. We

Figure 22 Screenshot of the adaptation accessibility metadata.

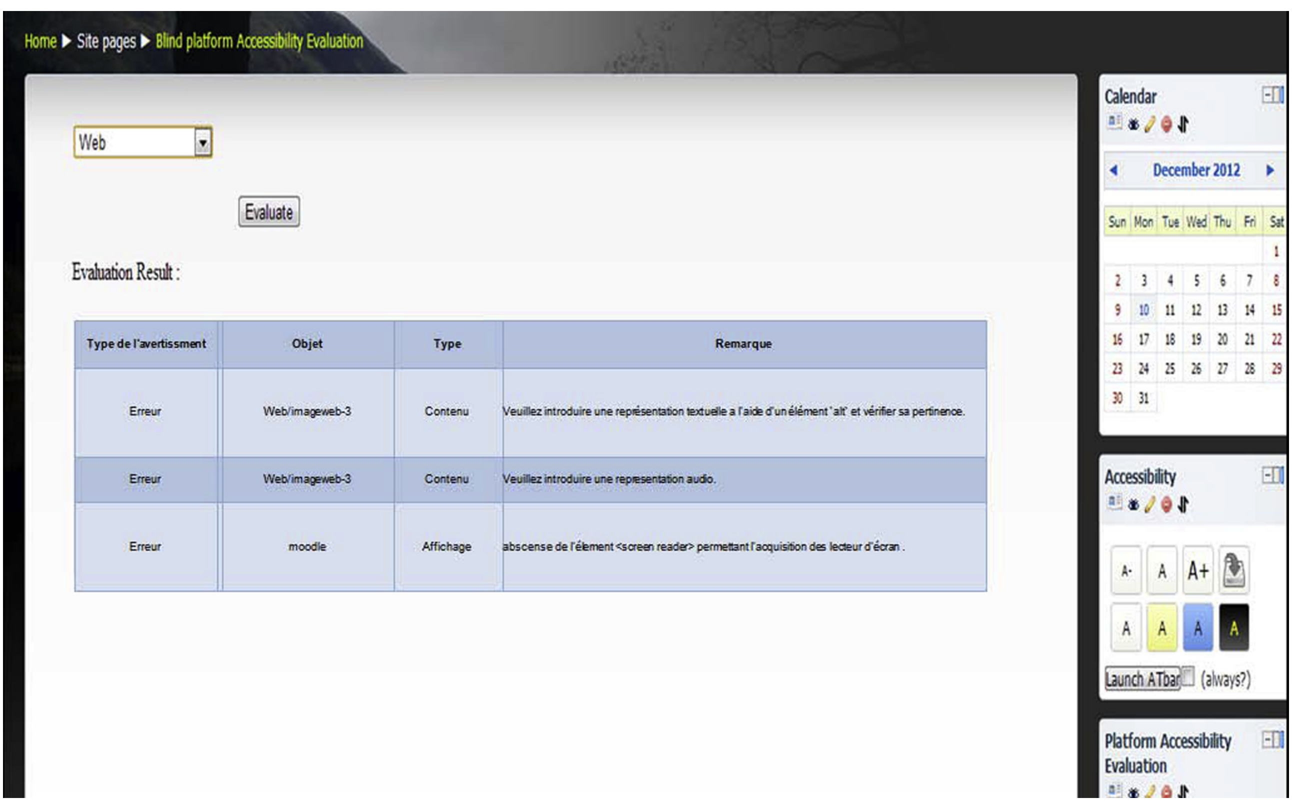

Figure 23 Screenshot of the blind platform accessibility evaluation report.

presented the *Moodle*$^{Acc+}$ as the accessible version of the Moodle platform as well as a debrief of the offered services within *Moodle*$^{Acc+}$. It is noteworthy that our work is not limited only to people with disabilities but it includes also anyone disabled by his/her context.

We expect that our contribution will empower the efforts deployed toward full inclusion of people with disabilities. The elaborated meta-model for accessible e-Learning systems helps to make automatic the generation of an accessible content, the conformance of the content to e-Learning and acces-

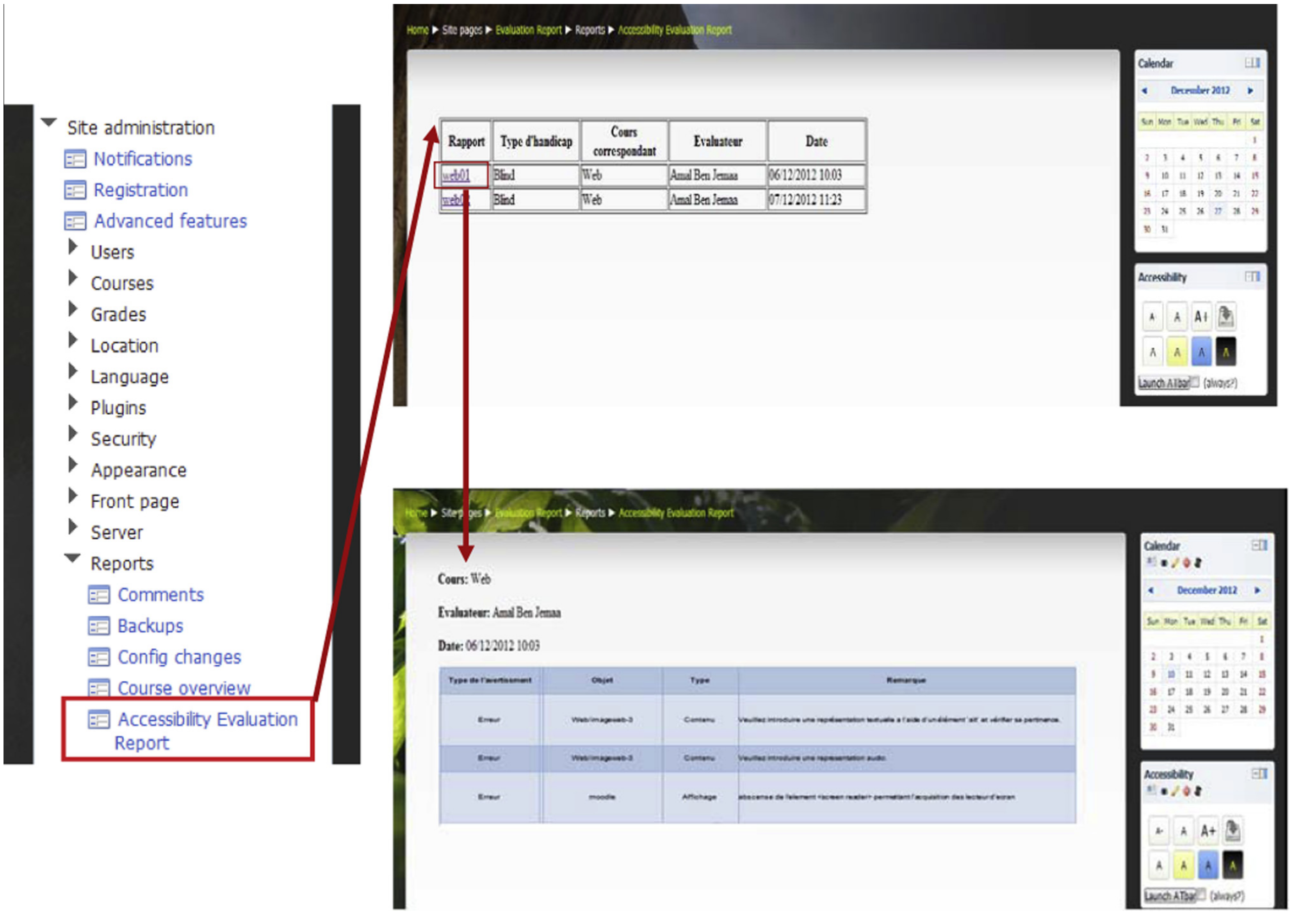

Figure 24 Screenshot of Platform accessibility evaluation report viewing.

sible properties as well as the transformation into an implementation adapted to specific needs and specific contexts. This meta-model supports accessible e-Learning application by adding two concepts: the concept of presentation ''Display'' and the concept of control ''Control''.

The presentation and control concepts were chosen taking into account their particularities for each type of disability. With the introduction of this meta-model, we avoid in particular ad hoc accessibility implementation since we are considering accessibility from an early stage of systems lifecycle and any generated system preserves the properties specified in the corresponding model and allows the preservation of these properties after any modification.

As a perspective of this work, we propose in the future to investigate the modeling transformation process from abstract models to specific models. In addition, we intend to extend the application of our approach to other e-Learning platforms with a special focus on mobile learning.

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