Evaluating the Accessibility of Three Open-Source Learning Content Management Systems: A Comparative Study

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ABSTRACT: Learning content management systems (LCMSs) have become increasingly popular in the educational field over the past few years. However, problems in system design can create difficulties in the interactions between LCMSs and an important sector of the user population. The assessment and monitoring of LCMS accessibility are vital for the guarantee of universal accessibility in education. This article presents a comparative study of the accessibility of three web-based, open-source LCMSs: Moodle, ATutor, and Sakai. Results of the study indicate that barriers to accessibility are present in each of the three systems evaluated. A primary aim of the study is to help detect and correct these barriers such that the goal of universal access in educational environments may one day be achieved. © 2011 Wiley Periodicals, Inc. Comput Appl Eng Educ 9999:1–8, 2011; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.20557

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INTRODUCTION

Over the past few years, the use of information and communication technology (ICT) has become ever more interwoven into the fabric of individuals' everyday lives. In the field of education, the use of e-learning systems [1] has increased exponentially thanks mainly to the proliferation of Internet use in the classroom [2–5].

Among the technologies having acquired particular importance in the field of e-learning are learning content management systems (LCMSs) [6]. As the majority of currently used LCMSs and their applications are web-based, the types of accessibility barriers present and users affected by such barriers are similar to those for other web-based technologies. Among the user groups most often affected by such barriers are people with disabilities (either permanent or temporary), the elderly with limited mobility and individuals with a low level of expertise using computers. In order to provide equal opportunities to all learners accessing educational information and instruction through LCMSs, as well as to all instructors responsible for sharing this information, all barriers to accessibility must be removed from learning environment.

For learners or instructors with disabilities, for example, accessible LCMSs must take into account certain assistive technologies (ATs)—such as screen readers, refreshable Braille displays, speech synthesizers, screen magnifiers, adaptable keyboards, and voice recognition software—used to help users see, hear, and interact with the information presented. In addition to physical barriers, the achievement of a fully accessible LCMS should also entail adjustments made with respect to a wide range of user intellectual capacities, interests, and learning styles (e.g., visual, auditory, or tactile) [7].

This article presents a comparative study of three web-based, open-source LCMSs as regards (1) their accessibility for authors in the course creation process and (2) the accessibility of the courses and learning materials created for users. This study would allow to identify the most suitable system for building accessible LCMS applications.

While more than six different LCMSs—including .LRN 2.4.1,[1] OpenACS 5.5.1,[2] ATutor 1.6.2,[3] Moodle 1.6,[4] and Sakai 2.6.0[5]—were originally considered, only the latter three systems were ultimately selected, a decision made on the basis of software type (i.e., open-source), use (i.e., wide use and popularity), and compliance with W3C accessibility standards and guidelines.

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[1].LRN 2.4.1 (2009), available at http://dotlrn.org/download.

[2]OpenACS 5.5.1 (2009), available at http://openacs.org/.

[3]ATutor 1.6.3 (2009), available at http://www.atutor.ca.

[4]Moodle 1.6 (2009), available at http://docs.moodle.org/es/Portada.

[5]Sakai Project 2.6.0 (2009), available at http://sakaiproject.org/portal.

With this goal, the next section of the article examines related works in the field of web accessibility. The study design, evaluation methods used, and parameters according to which systems were specifically evaluated are reviewed in the third section, while principal study results are presented in the fourth section. Finally, the fifth section discusses general conclusions and areas for future research.

RELATED WORK

As the rights of web users with disabilities have gained greater prominence and definition in anti-discrimination policies and legislation worldwide, accessibility has come to be identified as one of the principal requirements in the design of web-based systems and contents [8]. In the United States, for instance, the amended Section 508 of the Workforce Rehabilitation Act of 1973 [9] enhances access to broadband technology and services for people with disabilities. Despite the proliferation of such legislation, however, studies have repeatedly shown that web site accessibility is far to obtain an acceptable level of accuracy [10].

In order to achieve a more acceptable level of accessibility in LCMSs, therefore, additional standards must be followed. Such guidelines for web-based resources include standards from the World Wide Web Consortium (W3C)[6] and accessibility guidelines from the W3C's Web Accessibility Initiative (WAI),[7] generally, and the WAI's Authoring Tool Accessibility Guidelines (ATAG)[8] and Web Content Accessibility Guidelines (WCAG),[9] more specifically. Additionally, standards developed specifically for web-based learning applications include the Instructional Management System (IMS) Global Learning Consortium (GLC) Guidelines for Developing Accessible Learning Applications[10] as well as the Sharable Content Object Reference Model (SCORM)[11] for the building and management of learning systems.

Grounded in learning and accessibility standards like SCORM and the IMS GLC Guidelines and using the .LRN LCMS, *Formación Abierta Accesible* (FAA),[12] and Accessible Learning Platform for Europe (ALPE)[13] represent two important projects in the fields of web accessibility and e-learning undertaken by Spain's aDeNu (Adaptive Dynamic Online Educational Systems Based on User Modeling)[14] research and development group. Primary objectives in the former project focus on facilitating greater participation in educational websites by students with disabilities, whereas in the latter they center on improving the reuse of learning resources and the accessibility of system information.

Finally, European Unified Approach for Accessible Lifelong Learning (EU4ALL)[15] represents another important project in the field. Proposing the concept of accessible lifelong learning, EU4ALL seeks the elimination of barriers to the interlinked worlds of education and work through the use of appropriate technologies.

STUDY DESIGN

The study undertaken for the present article aims to evaluate and compare three selected LCMSs with respect to (1) their ability to develop accessible applications in accordance with the WCAG and (2) their general accessibility as authoring tools in accordance with the ATAG. Details regarding study design are presented in the sub-sections below.

Systems Studied

The three LCMSs evaluated and compared here were Moodle 1.9.4, ATutor 1.6.2, and Sakai 2.6.0. As explained earlier, their selection over other LCMSs was due to their status as internationally popular open-source systems that, to a certain extent, attempt to avoid barriers to accessibility.

Study Participants

The comparative study of the three LCMSs was carried out by two expert evaluators—with 2 and 5 years of professional experience, respectively—specializing in the analysis of accessibility levels in virtual learning environments.

Study Parameters

An LCMS is defined as accessible when its use makes the creation and management of accessible learning content possible for all. This is not to say, however, that all content created with accessible LCMSs will, therefore, necessarily be accessible. In practice, however, for most LCMSs the creation of accessible applications depends much more greatly on the experience and knowledge of the user with respect to web accessibility.

Taking these considerations into account, accessibility experts focused their evaluation and comparison of the three LCMSs around four basic parameters deemed to be essential for LCMS accessibility. Each of the four parameters selected were based on standards from the WCAG 1.0 [11] and ATAG 2.0 [12] as well as the evaluators' own professional experience in order to ensure the systems' current and future viability and scalability. Rather than conducting a lengthy analysis of LCMS compliance with each standard enumerated in the WCAG 1.0 and ATAG 2.0, the four parameters were selected by experts on the basis that the adaptation of an LCMS to remove accessibility barriers related to any of these parameters would require a high development cost and would only be viable through the use of open-source software. In Table 1, each study parameter is associated with its corresponding ATAG and WCAG guidelines or checkpoints. Priority levels are given for each.

[6]W3C, available at http://www.w3.org/.

[7]WAI from W3C, available at http://www.w3.org/WAI/.

[8]ATAG, available at http://www.w3.org/WAI/intro/atag.php.

[9]WCAG, available at http://www.w3.org/WAI/intro/wcag.php.

[10]IMS GLC, available at http://www.imsglobal.org/.

[11]SCORM, available at http://www.scorm.com/.

[12]FAA, available at http://adenu.ia.uned.es/faa/.

[13]ALPE, available at http://adenu.ia.uned.es/alpe/.

[14]aDeNu, available at https://adenu.ia.uned.es/web/en.

[15]EU4ALL, available at http://www.eu4all-project.eu/.

Table 1 ATAG 2.0 Guidelines/Checkpoints and WCAG 1.0 Checkpoints Associated With Study Parameters

Parameter	ATAG 2.0 guideline description	ATAG 2.0 details for advanced users[a]	WCAG 1.0 checkpoint description	WCAG 1.0 details for advanced users[b]
Accessible templates and themes	Authors must be supported in the production of accessible content with accessible templates and other pre-authored content (B.2.5)	Level A: B.2.5.1-2	Content must be presented in different ways without losing information or structure (5.1/5.2/6.1)	Priority 1: 4.1, 5.1, 5.2, 6.1
		Level AA: B.2.5.3-6	The content must be navigated sequentially (9.4)	Priority 2: 2.2, 3.2, 3.4, 11.1, 11.2
		Level AAA: B.2.5.7-9	The document must be well structured (3.2)	Priority 3: 4.3, 9.4
			The primary natural language of the web pages must be identified along the website (4.1/4.3)	
			Color contrast must be sufficient throughout the website (2.2)	
			Relative units must be used (3.4)	
			Available and appropriate W3C technologies should be used (11.1/11.2)	
Accessible content editor	The LCMS must ensure that automatically generated content is accessible (B.1.3)	Level A: B.2.1.1-3, B.2.2.1-3, B.2.3.1	Content must be presented in different ways without losing information or structure (5.1/5.2/5.5/5.6)	Priority 1: 1.1, 4.1, 5.1, 5.2
	The LCMS must guide the author to create and edit accessible content (B.2.1)	Level AA: B.1.3.2, B.2.2.24-8, B.2.3.2	Language and abbreviations must be identified along the website (4.1/4.2/4.3)	Priority 2: 3.5, 3.6, 3.7, 10.1, 10.2, 11.1, 11.2, 12.4, 13.1
	The LCMS must help authors detect accessibility problems (B.2.2) and repair them (B.2.3)	Level AAA: B.1.3.3, B.2.2.9-10, B.2.3.3	The document must be well tabbed (9.4)	Priority 3: 4.2, 4.3, 5.5, 5.6, 9.1, 9.4
			Headers, lists, and quotations must be represented properly (3.5/3.6/3.7)	
			Available and appropriate W3C technologies should be used (11.1/11.2)	
			The current window must not be changed without informing the user (10.1)	
			Each element must have a label and be well described (10.2/12.4/13.1/1.1)	
			Client-side image maps must be provided (9.1)	
Invasive JavaScript	N/A	Level: N/A	The LCMS must ensure that all dynamic contents show the same functionality when stopped or displayed in different devices (6.3/6.4/6.5/8.1/9.2/9.3)	Priority 1:6.3, 6.4, 8.1 Priority 2: 6.5, 8.1, 9.2, 9.3.
Tables for layout	N/A	Level: N/A	Content must be presented in different ways without losing information or structure (5.1/5.2/5.3/5.4)	Priority 1: 5.1, 5.2
			A linear text alternative must be provided (10.3)	Priority 2: 5.3, 5.4
				Priority 3: 10.3

[a]Minimum priority level is indicated by priorities belonging to conformance level A, while maximum priority level is indicated by priorities belonging to conformance level AAA.
[b]Level 1 represents the minimum priority level, while level 3 indicates the maximum priority level.

While the version of WCAG currently recommended by the W3C is WCAG 2.0 [13], the evaluation presented here was conducted according to the earlier version, WCAG 1.0. The decision to use the earlier version of WCAG responded to the fact that sufficiently mature evaluation methods and automatic tools for accessibility analysis according to WCAG 2.0 do not yet exist. At the same time, while the reference version of ATAG currently recommended by the W3C for the evaluation of authoring tool accessibility is ATAG 1.0 [14] the version is nevertheless ill-prepared for new technologies such as LCMSs. Thus, the ATAG 2.0 Working Draft was selected here due to its greater appropriateness for the study of LCMS compliance with accessibility standards.

The two first study parameters identified in the preceding table refer to the capability of the LCMS to support the production of accessible content, a necessary pre-requisite for viable systems. Web pages usually combine static and dynamic content. In LCMSs, static content is represented by templates and

themes, where the basic abstract structure of the web pages is fixed. Responding to this static content, the first study parameter focuses on the accessibility of LCMS templates and themes. Author-generated dynamic content, however, is added through the LCMS content editor. Thus, the second parameter of the study focuses on the accessibility of the LCMS content editor particularly with regard to the uploading of learning contents.

With regard to this first parameter, the lack of accessible themes or mechanisms for the creation/editing of themes in an LCMS represents a significant barrier to accessibility. In order to obtain accessible products, content must necessarily be separated from structure and presentation. It is for this reason that accessible templates and themes are indispensable elements of accessible LCMSs. According to ATAG 2.0 Principle B.2, ''[a]uthors must be supported in the production of accessible content.'' Authoring tools are responsible for the creation of accessibility barriers if they are automatically generated. Thus, according to the checkpoint B.2.5.1 of ATAG, ''[if an] authoring tool automatically selects templates or pre-authored content, then the selection meets WCAG 2.0 Level A when used. (Level A).'' The ATAG 2.0 checkpoint B.2.5.2 states that ''if [an] authoring tool provides templates, then there are accessible template options for a range of template uses. (Level A).'' Furthermore, if authors are provided a template selection mechanism that selection mechanism must indicate the template accessibility status (if known) as well as any accessible template options that are at least as viable as other options.

With regard to the second parameter, learning contents may be changed or adapted through the use of content editors which, in LCMSs, are usually of the type WYSIWYG (what you see is what you get). A WYSIWYG user interface displays the content being edited (to authors) in a way that is very similar to how it will appear to end users, facilitating the editing task. ATAG 2.0 guideline B.1.3 requires that authoring tools ensure that automatically generated content be accessible. The capacity of a content editor to guide the authors in the creation and editing of accessible content—helping the authors detect and solve any accessibility problems along the way—is looked on very positively by numerous ATAG 2.0 guidelines (B.1.3, B.2.1, B.2.2, and B.2.3). Furthermore, accessibility may be put at risk if certain editable features are not restricted insofar as authors—particularly non-expert authors in issues regarding accessibility—may inadvertently introduce additional barriers into the learning contents during the editing process.

Focusing on specific WCAG 1.0 guidelines, the latter two parameters chosen by accessibility experts respond to the need for accessible interfaces in LCMSs. The third parameter deals with the graceful transformation of LCMS pages featuring new technologies. A critical study parameter, the use of certain technologies—such as the very common JavaScript language—often results in the creation of important accessibility barriers when particular user agents—including ATs for people with disabilities—are used. In such a case, then, an alternative technology is required. The fourth study parameter deals with the proper use of markup and style sheets, as well as gracefully transformable tables. As discussed earlier, the separation between content and presentation constitutes one of the principal requisites for accessibility. According to the professional opinion of study experts, some of the most common barriers to accessibility present in web pages are those resulting from the use of tables for content layout. For that reason, they have been taken as a critical parameter for the present study.

With regard to the third study parameter, when used in LCMSs with particular user agents, JavaSript can run the risk of being disabled or not supported. As this constitutes an[Q2] important barrier to accessibility, an LCMS using JavaScript for the implementation of a particular feature must also offer an alternative to JavaScript for that implementation.

Finally, with regard to the fourth and final study parameter, the use of tables for content layout in LCMSs can oftentimes be impedimentary to full accessibility. The use of markup language for content presentation rather than solely for structural markup can make understanding table organization as well as table navigation particularly difficult or even impossible for users relying on specialized software. As it is highly advisable, therefore, that markup language be used only to structure tabular data, the use of tags according HTML specifications and CSS techniques for content layout represents a preferable alternative.

Evaluation Methods

For the study, experts formally evaluated the accessibility of each of the three open-source LCMSs (separately) using W3C methodology[Q3] **Error! Reference source not found**.taking WCAG 1.0 and ATAG 2.0 specifically into account. During this evaluation, the same learning platform—an example of a real teaching situation where a teacher uses instructions for the creation of new learning contents using editors and templates—was developed by experts using each of the three LCMSs.

Both automatic tools and manual techniques were used by experts for LCMS evaluations. Among the former group, both HERA[16] and *test de accesibilidad web* (TAW)[17] were used for the evaluation. To support additional manual evaluation of system accessibility, different development tools such as Accessible Information Solutions' Web Accessibility Toolbar[18] and the Firefox Accessibility Evaluation Toolbar[19] were used. Finally, content accessibility was also studied for different user agents (e.g., browsers and players) and ATs (e.g., screen readers and magnifiers) in order to evaluate system compliance with WCAG 1.0.

RESULTS

In this section, results from the qualitative analyses conducted of the three LCMSs with respect to each of the four study parameters are presented. Particular strengths and weaknesses of each system are also discussed. As explained in greater detail below, while many features in each of the three LCMSs were found to be accessible, general system accessibility in each case was nevertheless found to be of a limited scope.

[16]HERA, available at http://www.sidar.org/hera.

[17]TAW, available at http://www.tawdis.net/taw3/cms/es.

[18]AIS for Internet Explorer 1.2, available at http://www.technosite.es/descargas/WAT_ES_1.2.rar.

[19]Firefox Accessibility Evaluation Toolbar 1.5.61.0, available at https://addons.mozilla.org/es-ES/firefox/addon/accessibility-evaluation-toolb/.

Accessible Templates and Themes

The ATutor 1.6.2 LCMS includes several features—such as bypass links, accessibility verifiers, alternative text, and style sheets—intended to increase system accessibility. In each system theme, either a selection or the totality of these features can be found. The default theme, known as "ATutor," contains the totality of these functionalities and complies with ATAG 2.0 checkpoints B.2.5.1 and B.2.5.2 (both with conformance level A). While the use of the default theme appears highly recommendable for the building of an accessible system, the theme does not fully comply with WCAG 1.0 and, therefore, cannot be considered fully accessible. Despite the latter fact, the LCMS nevertheless allows the user to make the changes necessary for the obtainment of an accessible application. In addition, the ATutor system allows themes to be imported (from the platform), installed (from the application), exported, disabled, or deleted.

In Moodle 1.9.4 while multiple types of themes are offered and particular themes may be assigned to a particular course or user, no default theme with accessible interface is provided. The LCMS therefore fails the ATAG 2.0 checkpoint B.2.5.3 (conformance level AA). Additionally, despite the presence in Moodle of flexible themes such as "Chameleon," particular WCAG 1.0 guidelines (priority level 2) are nevertheless not satisfied. In order to solve these accessibility problems, study evaluators identified two possible approaches: (1) the author could edit the Chameleon theme to solve accessibility problems or (2) the author could create a new, accessible theme and include it in Moodle.

Unlike the previous two systems discussed, Sakai 2.6.0 contains no explicit section for themes in its interface. As a result, the process of changing system appearance in Sakai is somewhat less intuitive. In the absence of a themes section in the system, a change must be made to the "sakai.properties" file (i.e., the file where system interface properties are placed). This implementation, known as "skin," makes use of CSS and XML files. In Sakai, where each skin has an image directory and three CSS files, it is possible to assign different skins to different pages (an option not available with ATutor or Moodle). In order to change the appearance of the site and in compliance with WCAG 1.0 guideline 3.1 (priority level 2), the default skin, known as "default," can be edited and the CSS files can be modified by the author. Nevertheless, if the author wants to include a new skin with accessible CSS files, the Sakai source code must be edited, requiring prior knowledge of programming and accessibility issues. Finally, only CSS files may be used and no files for the definition of a new logical structure for contents (e.g., header, footer, and side) can be included.

Inclusion of Invasive JavaScript Causes Accessibility Problems

In ATutor 1.6.2, while JavaScript is implemented to activate links and guide the system, an implementation alternative is nevertheless provided. In this way, links may be accessed and the system guided even when the JavaScript option has been disabled in the user agent. As a result, the system is in compliance with the WCAG 1.0 checkpoints 6.3 and 8.1 (priority level 1).

In Moodle1.9.4, while JavaScript is used to display menu items where system functionality can be found, the system also offers an alternative. Thus, when JavaScript is disabled in the user agent, menu items are still displayed. In this respect, Moodle 1.9.4 is similar to ATutor 1.6.2 for its compliance with WCAG 1.0 checkpoints 6.3 and 8.1. JavaScript is also implemented in the Moodle help guide with a corresponding alternative offered. Nevertheless and in contrast to the previous example of JavaScript in Moodle, when this latter instance of JavaScript is disabled, the button used to close the help guide window stops working. In this respect, Moodle 1.9.4 does not completely comply with WCAG 1.0 checkpoint 6.4 (priority level 2). A third implementation of JavaScript in Moodle is to hide the "Block Context." As opposed to the other instances of JavaScript in the system, however, Moodle provides no alternative here and the feature stops working altogether when JavaScript is disabled in the user agent. This is another instance in which Moodle does not fully comply to WCAG 1.0 checkpoints 6.3 or 8.1. Finally, as Moodle does not use JavaScript to activate links, no barriers to accessibility are present in the feature.

In Sakai 2.6.0, the third LCMS analyzed, JavaScript is used in every link for managing new content. Furthermore, when JavaScript is disabled in the user agent, all of these features stop working. It is clear that JavaScript use here represents a major and overarching barrier to system accessibility since no courses can be added to the platform when JavaScript is disabled. The problem persists in every system feature related to the editing and deletion of content. While JavaScript is used for other aspects of the LCMS such as online help, Sakai nevertheless offers an alternative solution in those cases such that the services may accessed correctly.

Finally and with respect to the WYSIWYG editors, an important accessibility problem was observed in each of the three LCMSs evaluated; namely, the HTML editors cannot be used when the JavaScript option is disabled in the user agent, indicating a failure to conform to WCAG 1.0 checkpoint 6.4. While the three LCMSs provide a text area as an alternative for the editing of contents, such a solution would nevertheless put accessibility at risk when the author has no knowledge about HTML or WCAG.

Use of Tables for Content Layout

Neither ATutor 1.6.2 nor Sakai 2.6.0 use tables for content layout. Rather, in both systems elements are used according to HTML specification and CSS techniques. Therefore, the use of tables by both systems is correct and conforms to WCAG 1.0 checkpoints 5.1 and 5.2 (priority level 1). However, in some cases ATutor 1.6.2 includes style attributes in the page code, such as "align" for elements, rather than including the presentation in CSS. These types of attributes are not recommended in WCAG 1.0 and do not comply with checkpoint 11.2 (priority level 2). These attributes could pose compatibility problems with the latest versions of HTML (i.e., HTML 4.01 and above) and therefore present accessibility barriers for the LCMS.

Regarding table markup, ATutor uses the "scope" attribute to help screen readers associate a data cell with the appropriate headers. This attribute can be used instead of the "headers" attribute without accessibility problems. Additionally, in Sakai, screen readers can access table contents without accessibility problems through the "id" and "heading" attributes. Thus, both systems allow users with visual impairments to access table contents through screen readers without barriers to accessibility, satisfying WCAG 1.0 checkpoint 5.2.

In Moodle1.9.4, however, tables of one row with two cells are used for the layout of the site, where one cell is used for side menus and the other for main content of the web page. Furthermore, certain web content, such as calendars, is also organized with tables in Moodle. Nevertheless, as checkpoints 5.3 and 5.4 (priority level 2) of WCAG 1.0 specify that systems are accessible if the content structured by tables is understandable when read line to line, no barriers to accessibility exist here. In the remainder of the cases, Moodle correctly uses elements and CSS styles. However and as with ATutor, in some cases Moodle includes style attributes such as ''valign'' or HTML elements such as <font> that do not satisfy WCAG 1.0 checkpoint 11.2.

Additionally, while Moodle used relative units for the majority of the system's functionalities, other functionalities such as the calendar use absolute units. This can be problematic for users with visual impairments. In one example, if a visually impaired user attempts to increase web page text size in a browser, all the other information displayed will be shown in that larger font, as well. In a final positive note and as with ATutor, Moodle also includes the ''scope'' attribute in tables.

Accessible Content Editor

In the three LCMSs evaluated, a default WYSIWYG content editor is provided, each with its own accessibility problems. With regard to the separation of content and presentation, a necessary feature in order to guarantee accessibility, the ATutor 1.6.2 content editor is robust. Content and presentation are kept separate and styles for content editing are offered and included in the CSS file. This latter feature is particularly helpful for content accessibility, since headings, paragraphs, fonts, and all text and background colors are included in HTML through the ''style'' attribute.

The case of Moodle 1.9.4 and Sakai 2.6.0 content editors, however, is quite different in that content and presentation are not separate, a failure of compliance with WCAG 1.0 checkpoint 11.2. In the Moodle editor, colors and fonts are included in HTML with the <font> element (as opposed to the use of CSS styles); whereas in Sakai, not only background colors and fonts, but also all text are included in the <font> element.

When an author wants to add an image to the web content, the ATutor content editor asks that an alternative description of the image be provided, satisfying WCAG 1.0 checkpoint 1.1 (priority level 1). Furthermore, if this alternative description is not provided with the addition of the image, a warning message appears indicating that the image may not be accessible to certain users with disabilities. As the content editor prevents errors from being committed, ATAG 2.0 guidelines B.2.2 and B.2.3 (including checkpoints with conformance levels ranging from A to AAA) are satisfied. While alternative image descriptions are also allowed in Moodle and Sakai, satisfying WCAG 1.0 checkpoint 1.1, no warning message is provided to indicate a missing alternative image descriptions. Thus, the two LCMSs do not prevent against author error with respect to accessible image contents.

Concerning the addition of links to web content, all three LCMS content editors allow for the inclusion of titles for each link, satisfying WCAG 1.0 checkpoint 13.2 (priority level 2). However, none of the three systems contain a mechanism preventing title omission accessibility errors from being made. In this way, all three LCMSs fail to conform with ATAG 2.0 guidelines B.2.2 and B.2.3.

Another difference between systems noted by evaluators is that ATutor proposes to add navigation information and other accessibility features that Moodle and Sakai do not. For instance, the ATutor content editors allow for the addition of information for the ''tabindex'' and ''accesskey'' attributes, satisfying WCAG 1.0 checkpoints 9.4 and 9.5 (priority level 3). Furthermore, events may also be added to achieve device independence from an image or a link, satisfying WCAG 1.0 checkpoint 6.4.

With respect to support provided for accessible content, the ATutor and Moodle editors permit the inclusion of the ''lang'' attribute indicating system content language. This inclusion satisfies WCAG 1.0 checkpoint 4.1 (priority level 1). An important observed weakness of Sakai, however, is that its editor does not allow for such an addition. As for the markup of quotations covered under WCAG 1.0 checkpoint 3.7 (priority level 2), the ATutor editor uses the <blockquote> tag correctly to identify a text block as a quotation. On the other hand, Moodle and Sakai do not, using the <blockquote> tag instead simply to achieve a visual effect. While ATutor complies with checkpoint 3.7, therefore, Moodle and Sakai do not. Finally, as regards the addition of acronyms and abbreviations and the inclusion of the ''summary'' attribute for tables, addressed by WCAG 1.0 checkpoints 4.2 and 5.5 (both with priority level 3), respectively, ATutor is in full conformance. Moodle, on the other hand, only allows for the addition of the ''summary'' attribute for tables and no warning is given if the attribute is not included. Sakai does not allow for the addition of this last attribute.

As for the accessibility of elements in the editor, each of the three LCMS editors offer descriptions of all elements included therein such that they may be easily understood by a screen reader. Additionally, access keys are given for certain font styles such as bold, italic, and underline in compliance with WCAG 1.0 checkpoint 9.1 (priority level 3). In addition, Moodle enables a keyboard-friendly editor which provides shortcut keys to facilitate content editing. Limitations are nevertheless present in this functionality including, for example, the lack of defined shortcuts for table editing.

With regard to the visual aspect of the editor, ATutor permits changes in settings used to control colors and displayed fonts, in compliance with WCAG 1.0 checkpoint 1.1. Although these setting options are not available for the configuration of the HTML editor itself, authors can nevertheless change Style settings for the entire site in order to achieve an ideal color contrast. Moodle, on the other hand, does permit the selection of colors for the editor's text area, presenting an interesting option in cases where an ideal color contrast is required. Additionally, Moodle offers the possibility to disable the use of its default editor. Evaluators observed none of these functionalities in Sakai.

In contrast to the other LCMSs studied, Moodle also allows for the configuration of editing options offered to different authors, such that functionalities may be limited and the inclusion of certain elements in the editor may be disabled depending on the authors' profile. So long as it does not prevent the user from carrying out necessary tasks, this capability could prove advantageous for ensuring the accessibility of the platform.

Perhaps the most important feature of the ATutor content editor compared to those of the other systems studied is its capability to check content accessibility, in conformance with ATAG 2.0 checkpoint B.2.2.1 (conformance level A). Similar to most of the editors used by the LCMSs, the ATutor content editor allows for the inclusion of accessible content without limiting the author's actions. It is, therefore, possible and quite commonplace that additional accessibility errors be introduced in the HTML code in the process. Nevertheless and as a result of this functionality of the ATutor editor, content can be reviewed and modified if accessibility problems are detected.

Summary of Findings

In Table 2, results discussed in the previous sub-sections are summarized for each system and parameter tested. The result displayed in each cell of the table indicates if a particular study parameter has been met by a particular LCMS. However, where a simple *yes*/*no* indication is not possible for a particular cell due to the presence of exceptions during testing (explained in detail in earlier sub-sections), this has been indicated in the table with an asterisk.

Analyzing the information presented in the table and earlier sub-sections, the following five points may be noted:

- *Providing accessible templates*. ATutor is the only LCMS evaluated that provides an accessible template. However, some template features require further improvement.
- *Editing and creating new templates*. All three LCMSs provide a high level of flexibility. Template use in Sakai, however, is different from that of Moodle and ATutor, potentially making familiarization with system use more complicated. Moreover, Sakai templates are composed of only CSS files. Overall structure of the site is, therefore, not directly related to the template and modification of source files could be required.
- *Use of JavaScript language*. JavaScript is used by all three LCMSs; however, an implementation alternative is not always provided. This is one of the principal limitations of ATutor and Sakai. Used, for example, in the ATutor log-in process, this process stops functioning correctly when the JavaScript option is disabled in the user agent. Despite the inconvenience, however, ATutor provides alternative solutions when using JavaScript within the application. In Sakai, the invasive use of JavaScript is one of the most important features of the system for which no alternative is provided. In Moodle, however, an alternative is sometimes offered when JavaScript is used. One such example is for links (other LCMSs do not offer an alternative here). For this reason, JavaScript accessibility failures observed in Moodle are not particularly troubling. They should nevertheless be solved in order to achieve full accessibility.
- *Use of tables for content layout*. Neither ATutor nor Sakai use tables for content layout. While Moodle does use tables in this way, table content can nevertheless be understood when read line by line.
- *Accessible content editor.* ATutor provides a number of interesting features meant to ensure platform accessibility. While Moodle and Sakai provide some accessibility features, they do not offer enough since author knowledge of the WCAG is assumed. It must be remarked, however, that Moodle's editor can be configured. Finally, the required use of JavaScript for each of the systems' WYSIWYG editors and the accompanying accessibility problems posed must also be considered.

CONCLUSIONS

The study presented here has attempted to demonstrate the strengths and weaknesses of three open-source LCMSs—Moodle 1.9.4, ATutor 1.6.2, and Sakai 2.6.0—as regards the compliance of each system with ATAG 2.0 and each system's user interface with WCAG 1.0. Results obtained from the

Table 2 A Comparative Table of LCMSs and Parameters Evaluated

	ATutor 1.6.2	Moodle 1.9.4	Sakai 2.5.4
Parameter 1: Accessible templates			
Includes accessible themes	✓[a]	✗	✗
Enables editing of templates	✓	✓	✓
Enables creation of new templates	✓	✓	✓
Parameter 2: Invasive JavaScript			
Uses JavaScript and provides an alternative	✓[a]	✓[a]	✗
Parameter 3: Tables for layout			
Does not use tables for layout of content	✓	✓[a]	✓
Parameter 4: Accessible content editor			
Can be configured	✗	✓	✗
Does not require JavaScript for use	✗[a]	✗[a]	✗[a]
Includes accessibility features for users with disabilities	✓	✓[a]	✓[a]
Includes editing process to provide accessible content	✓	✗[a]	✗[a]
Does not depend on user's knowledge of WCAG	✓[a]	✗	✗

[a]With exceptions.

independent accessibility evaluations of each LCMS have been presented, summarized, and compared in order to identify the most suitable system for building accessible LCMS applications. To this end, results suggest that ATutor is likely the system which facilitates the creation of accessible learning content to a greater degree than the other two LCMSs studied. In each of the three systems studied, however, problems were observed that would likely limit their accessibility for certain groups of users like elderly people and people with disabilities (either temporary or permanent). Such barriers to accessibility could have the effect of partially or completely excluding these users from interaction with the learning environment.

Hoping that the results of the present study may prove useful to a diverse group of readers, the authors propose the following possible uses for the results and conclusions presented: (1) to permit users to determine whether any of the LCMSs studied is nearly accessible or far from accessible, (2) to guide users in the selection of one of the LCMSs evaluated over another according to specific learning system aims, and (3) to help system developers resolve accessibility problems detected (and compared with other systems' implementations). Perhaps this final point is most important since the removal of accessibility barriers is essential for the ultimate achievement of universal access to learning environments.

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