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Adaptation of the E-Learning Exercise Creator to the Needs of People with Disabilities with Impaired Access to Education

Abstract

This article focuses on the implementation of the WCAG (Web Content Accessibility Guidelines) 2.1 guidelines into e-learning courses. The Quizer e-learning platform, which enables the creation of interactive multimedia courses, has provided the basis for the introduction of the WCAG component. The platform includes two basic tools: an exercise creator and an exercise presenter. Once the Quizer Platform Exercise Wizard was analysed, a component was conceptualised and implemented to create e-learning courses compliant with WCAG guidelines and dedicated to people with disabilities. The technology for the implementation of this component was also presented. The function and validity of navigation through the courses using the keyboard and the use of screen readers were discussed as well. The research on the correctness of the WCAG standard implementation into e-learning courses was conducted with the use of designed cyber security quizzes. The final results of quizzes prepared according to WCAG guidelines and without WCAG were also compared. The research involved students majoring in computer science at Lublin University of Technology. Its results indicate the validity of using

the WCAG guidelines in the design of educational content for students with disabilities and equalizing their educational opportunities.

K e y w o r d s: e-learning, exercise creator, multimedia courses, WCAG

Introduction

Digital accessibility is currently one of the most important features of the content of websites, computer programs and mobile applications. This also applies to e-learning applications and platforms. The content, platforms and tools used in e-learning should be accessible to everyone, regardless of their skills, disabilities, equipment or other limitations. Failure to meet the digital accessibility standards in e-learning may cause difficulties in accessing education, in particular for people with disabilities, such as vision, hearing and mobility impairments. According to the data of the Statistical Office in Poland, in the academic year 2021/22, 19.9 thousand people with disabilities were educated at universities (1.7% of the total number of students). At many universities in this period, remote or mixed teaching was in force (some classes were held on-site and some remotely). The transition to distance learning on such a huge scale has caused many difficulties. One of them was often the lack of digital accessibility according to the applicable guidelines of the WCAG 2.1 standard. The then ongoing SARS-CoV-2 virus pandemic showed that the need to switch from higher education to remote learning should also take into account the needs and capabilities of people with disabilities in access to education. Therefore, an important topic in the area of e-learning is the development of digital accessibility of the solutions offered and determining its impact on the education of people with disabilities. It is worth emphasizing that digital accessibility is not only often a legal requirement, but also a moral responsibility enabling education for everyone, regardless of their individual limitations. Therefore, e-learning content creators should regularly test the digital accessibility of their materials, including interactive elements such as quizzes. It is important that people with different needs have equal opportunities to participate and understand this content.

The main aim of the article was to:

1. Create a component compatible with the interactive platform Quizer.pl that enables the creation of interactive exercises adapted to the WCAG 2.1 guidelines for people with disabilities, mainly visual impairments.
2. Assess the correctness of implementing the WCAG component into the Quizer elearning platform based on the feedback from users of cybersecurity courses.

The research questions RQ1-RQ5 of this study are:

RQ1. What specific elements and tools in the Quizer platform do need to be adapted to enable compliance with the WCAG 2.1 guidelines?
RQ2. What are the reactions and opinions of IT students about the new e-learning courses adapted to the needs of people with visual impairments?
RQ3. Did students with simulated visual impairment experience improvement in access to education thanks to the use of WCAG 2.1 in the designed e-learning courses?
RQ4. Does the use of WCAG guidelines in quiz preparation and presentation affect the results achieved by people with disabilities compared to the results of people using a standard quiz without WCAG?
RQ5. How did the students assess the correctness of the implementation of the WCAG 2.1 standard in the created quizzes from the point of view of cybersecurity?

The hypotheses H1-H4 of the research are:

H1. Adaptation of the Quizer e-learning platform to the WCAG 2.1 guidelines will have a positive impact on the accessibility of education for people with visual impairments who have difficult access to education.
H2. Creating dedicated e-learning courses in accordance with WCAG 2.1 guidelines will contribute to increasing the participation of people with visual impairments in the educational process.
H3. Preparing the quiz in accordance with WCAG guidelines will allow people with disabilities to achieve results at a level comparable to the results of people using a standard quiz without WCAG.
H4. The functionality of keyboard navigation and screen reader support in WCAG 2.1 compliant e-learning courses will be effective for people with various types of vision impairment.

Research Background

Many scientific articles discuss and examine the quality of life (QoL) of students with disabilities and their access to education (Chatzoglou et al., 2023). Madhesh in his work (Madhesh et al., 2023) points to a clearly lower quality of life (QoL) of students with disabilities at Shaqra University in Saudi Arabia. The factors mentioned include the failure to take into account all the needs of students with disabilities and low awareness among lecturers and peers of disabilities and their impact on the learning process. It further indicates that curricula and teaching tools did not meet the needs of these students and their demands for equal access. Contreras et al. documented in their study (Contreras et al., 2023) the significant impact of the pandemic on access to higher education for students with disabilities

in Chile. The access to education was limited for everyone, and it especially affected students with disabilities. As a conclusion, they emphasized the need for further actions aimed at increasing access to education and equalizing opportunities. Brain and Mariani in their work (Brain & Mariani, 2023) analyse the difficulties in equalizing accessibility for students with disabilities in Australia. They point out that despite government support, there are still significant differences between students without and with disabilities in terms of access to education, quality of life and educational achievements. Rizk and Hillier in their work (Rizk & Hillier, 2022) describe the roles of digital technologies in improving access to education and engagement of students with disabilities. Research shows that digital technology provides significant support for students with disabilities, enabling them to actively participate in classroom activities. The authors note that the use of IT tools significantly increases the interaction between students with disabilities and teachers and their peers. Despite progress in equalizing access to education for students with disabilities around the world, there is still a need for further work in this area. The development of programs, methods, teaching tools and courses that take into account the needs of these people undoubtedly contributes to equal educational opportunities. Burgstahler et al. (2004) emphasize in their work that distance learning creates learning opportunities for everyone if accessibility issues are taken into account in the process of designing university courses. Otherwise, unnecessary barriers may arise that hinder equal participation in education and careers for potential students and teachers with disabilities.

In today's society, the development of information and communication technologies plays an important role in many areas of life, such as medicine (Kabyshev & Kovalchuk, 2019), industry (Mon & René Del Giorgio, 2021), interpersonal communication (Lee, 2023), and organizational management. However, one area where the impact of these technologies is particularly evident is education (Fernández-Gutiérrez et al., 2020; Val et al., 2010; Rosa & Obillos, 2016), and specifically the development of e-learning, which is teaching based on internet technologies (Alfonso & Garcia, 2015; Petrovic et al., 2014). E-learning offers numerous benefits, such as accessibility, time and geographic flexibility, as well as individualization of the learning process (Stofkova et al., 2017). Through e-learning, students have the opportunity to acquire knowledge and skills in a flexible manner, tailored to their individual needs and pace of work. Regardless of location or time, education can be obtained remotely, using interactive e-learning platforms, video conferences, multimedia materials, and other digital tools. E-learning also enables access to diverse educational content, both in the form of online courses and self-study materials. As a result, students have the chance to develop their skills in various fields, regardless of the availability of local schools or universities. However, despite these advantages, many people with disabilities face barriers to accessing elearning-based education due to limitations resulting from their disabilities (Calvo et al., 2012). The World Health Organization estimates that over one billion peo-

ple worldwide experience some form of disability, and approximately 93 million children live with disabilities that affect their access to education. People with disabilities have various types and degrees of limitations that may affect their ability to engage with traditional teaching methods. Some of these limitations may stem from difficulties in physical access to buildings, visual or hearing impairments, cognitive disorders, or difficulties in interacting with computers. Many individuals with disabilities experience barriers to accessing education at different stages of life, leading to social exclusion and hindering the acquisition of qualifications and skills needed in the job market.

To mitigate these inequalities and ensure equal access to education for all, there is a need to develop educational tools and e-learning platforms that cater to the needs of people with disabilities (Ulbricht et al., 2011; Maćkowski et al., 2018). One such tool is the e-learning exercise creator, which enables the creation of interactive educational tasks and materials. However, many existing e-learning exercise creators do not meet the accessibility standards for people with disabilities, such as the guidelines specified in WCAG 2.1 (Web Content Accessibility Guidelines) (Germano & Silveira, 2022). WCAG 2.1 is an international standard that defines guidelines for web content accessibility for people with disabilities (Fernandez-Diaz et al., 2019; Sanchez et al., 2022). These guidelines address accessibility issues related to vision, hearing, speech, learning, cognition, mobility, language, and neurological impairments. Disabilities can occur singly or in complex forms, comprising multiple disabilities with varying degrees of severity. Each type of disability requires the application of different techniques to enable access to information on websites. Success criteria are specified for each guideline (Aizpurua et al., 2016; Filipe et al., 2023). This allows for the application of the WCAG standard in developed solutions and the verification of their compliance with the guidelines. The WCAG 2.1 guidelines define three levels of conformance: A (lowest), AA, and AAA (highest). It is important to note that achieving content compliance at the highest level (AAA) does not guarantee accessibility for individuals with all types and degrees of disabilities, especially those with complex disabilities. The design of software and e-learning courses should also take into account the needs of people with disabilities (Romero Mariño et al., 2018; Persson et al., 2015). This standard focuses on ensuring that individuals with different types of disabilities can access online content without any limitations. Adapting e-learning exercise creator tools to incorporate WCAG guidelines aims to enhance accessibility for people with disabilities, allowing them to use these educational tools on an equal basis with able-bodied individuals (Laabidi et al., 2014). Consequently, work is being done to develop new educational tools and e-learning platforms tailored to the needs of people with disabilities, as well as to examine the accessibility of existing ones. The authors of a study (Bocevska et al., 2018) analyzed the accessibility of recent public platforms, such as Moodle, Eliademy, Docebo, Sakai, and ATutor, for people with disabilities. They observed that the considered criteria have varying levels of

compliance with the guidelines for web content accessibility (WCAG) 2.0. The analysis focused on visual, auditory, and motor impairments. Accessibility testing of the Moodle system, specifically for visual impairments, was also conducted in another study (Armano et al., 2018). Four individuals with varying degrees of visual impairment participated in the study. Królak and Zając (Królak & Zając, 2022) conducted an analysis of Massive Open Online Courses (MOOCs) available on the Coursera platform in terms of their accessibility for users with disabilities. MOOCs are courses available to a large number of participants via the internet. The analysis was conducted in accordance with guidelines developed by the World Wide Web in three ways: user testing, heuristic evaluation, and automated auditing using various web tools. Despite the continuous development of the Coursera platform, the introduction of new improvements, and the implementation of accessibility policies, study participants still encountered barriers in terms of digital accessibility. An article by Seale & Cooper (2010) reviewed a range of tools that facilitate the work of teachers in higher education and enable the development of accessible e-learning materials and activities for students with disabilities. Brown et al.(2022) presented the fundamental principles of digital accessibility and the standards by which it is defined, as well as the technologies used by individuals with disabilities to interact with the online world. Reflecting on their own experiences with digital accessibility in the university sector, the authors propose a four-quadrant model of institutional support for accessible online teaching.

The e-learning exercise creator plays a crucial role in the instructional process by providing interactive learning and assessment materials. Adapting this tool to the needs of people with disabilities can improve their educational experiences and ensure equal opportunities for educational advancement. Various adaptations can be considered, such as providing alternative formats for textual and multimedia content, incorporating technologies that assist with navigation and interaction, and implementing user-friendly interfaces that prioritize usability and accessibility (Yang et al., 2023). Adapting the e-learning exercise creator to the needs of people with disabilities is not only important from the perspective of access to education but also a step towards building a more inclusive society. Ensuring equal access to education for all individuals, regardless of their disabilities, contributes to the development of their potential, social integration, and increased opportunities for full participation in society.

Methodology of Research

General Background. Selection of technologies for building the WCAG component

When creating the software and e-learning courses, the WCAG 2.1 guidelines were taken into account, thereby enabling the accessibility of course content for individuals with disabilities, primarily visual impairments. The basis for introducing the WCAG component was the Quizer e-learning platform (Quizer, n.d.), which allows for the creation of interactive multimedia courses. The platform consists of: "Exercise Creator" and "Presenter". The Quizer platform operates on the Oktawave cloud infrastructure, providing consistent platform support across various devices such as PCs, laptops, tablets, and smartphones. The virtual server of the Quizer platform application runs on the Linux-Debian operating system. The development of the platform utilized programming technologies such as Backbone JS, Bootstrap, PHP language, Laravel framework, and MySQL (Dziedzic, 2021). Users can create their individual accounts and gain access to the platform's resources. The "Interactive Exercise Creator" on the Quizer.pl platform enables the creation of presentations and interactive exercises. It allows for the creation of exercises such as pick one, pick many, drag and drop, fill in the blanks, or connect with lines. The "Interactive Exercise Creator" consists of content management modules and an editor for creating courses that facilitate data exchange between the portal and publishing (Dziedzic, Gudków & Wiśniewski, 2020). The diagram of the "Exercise Creator" is shown in Figure 1.

To enable the creation and solution of quizzes in accordance with WCAG guidelines, the following modifications were necessary in the "Exercise Creator" tool:

3. Development of a WCAG component that allows for keyboard and screen reader support in courses, as well as designing courses compliant with WCAG 2.1 guidelines, followed by its implementation into the "Exercise Creator" tool.
4. Addition of a WCAG tab to the Exercise Creator with the ability to enter alternative texts and indicate which elements should be considered by the screen reader. By utilizing an alternative text, non-text elements such as images, decorative graphics, icons, charts, animations, etc., can be processed by the screen reader and provide information about their content.
5. Enabling the screen reader to interpret the HTML code of the exercise and read alternative texts.
6. Allowing for the highlighting of selected elements to visually indicate the currently active element for visually impaired users.
7. Providing the ability to adjust and assess the contrast according to WCAG guidelines for the designed courses.

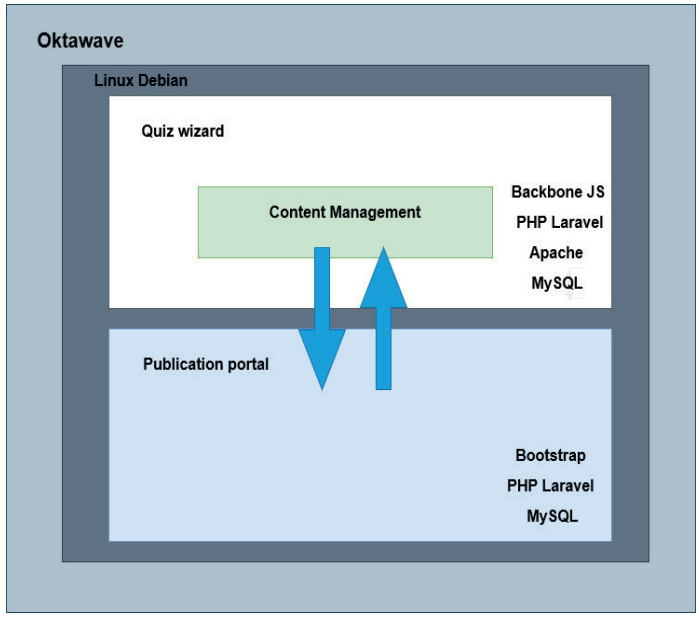

Figure 1. General schematic of the construction of the "Exercise Creator" in the Quizer e-learning platform

S o u r c e: Own work.

The frontend part of the "Exercise Creator" is built using Backbone JS technology. All modifications and new modules were also implemented using Backbone JS to ensure compatibility. Most of the platform's user interface components are programmed in JavaScript. The application incorporates elements such as components, containers, and triggers. A component is a software fragment that can be independently mounted into larger programs, while containers oversee the execution of the component and are implemented by application servers. Triggers are procedures that are automatically executed in response to certain events (Figure 2). Backbone JS is a programming library (framework) that utilizes a model-based data structure. Models are used to perform specific operations, and whenever a user interface action results in a change to a model's attribute, the model triggers a "change" event. All views that display the model's state can be notified of the change, allowing them to react accordingly by re-rendering the model with the updated data. Backbone JS applications follow a structure divided into controllers, views, and models. Backbone JS is event-driven, with events being triggered by changes in data models. All Backbone JS events are described using an event map.

One of the key elements of WCAG guidelines that addresses the needs of individuals with visual impairments is the appropriate contrast of the content presented. This also applies to e-learning courses, where inadequate contrast can limit or prevent the use of the course. In the "Exercise Creator," a component has been

implemented to assess and adjust the contrast of individual elements in relation to each other, ensuring that the designed courses meet specified visibility guidelines. The component is integrated within the "Exercise Creator" and is available upon request for course designers. It was developed in JavaScript, allowing for seamless integration with the Backbone JS framework.

Procedure for designing e-learning quizzes according to WCAG

Tests were conducted using two designed quizzes on the topic of cybersecurity: Types and Identification of Threats in the Network - Phishing. Phishing is currently a very popular method of fraud. The scammer impersonates another person or institution in order to obtain confidential information, infect the computer with malware, or persuade the victim to perform specific actions. The first quiz provided basic information about Phishing. The user's task was to familiarize themselves with or listen to all the information contained in the quiz. The second quiz involved selecting the correct answer to the given questions. The type of quiz used was Pick One (simple choice). To navigate through the courses, appropriate keys and keyboard shortcuts were defined. The following keys and shortcuts were adopted: TAB - to move to the next element on the timeline, SHIFT+TAB - to go back one element, SPACE - to select an answer and confirm the choice. In accordance with the logic of arranging elements in layers on the timeline in the "Quiz Creator" tool, this number of navigation keys is sufficient. As a result, exercising is intuitive for the user, even during their first interaction with the exercise. Additionally, these keys are commonly used for navigating web pages, so users who access online resources navigate through the exercises intuitively and in accordance with familiar procedures. When creating the quiz, all textual, graphical, and auditory elements were added to the stage and arranged on the timeline in layers, planning the TAB navigation path through the elements. The elements that are to be read by a screen reader should be selected and their alternative text should be entered in the WCAG tab. It is also necessary to add user variables to the project, which will store information about which the answer has been selected during the task solving process. Next, triggers were added to each answer checkbox so that specific fields change their state to selected, simultaneously resetting the remaining answers to their initial state. These actions must also include operations on variables that will change along with the user's selection and answer changes. Triggers were added to the button that checks and confirms the user's choice, displaying correct or negative feedback. In the case of the pick one exercise, additional conditions do not need to be applied. The view of the window for the designed quiz with arranged elements on layers on the timeline and adding a trigger is presented in Figure 2. The trigger is supposed to perform the action of showing or hiding objects when a particular object is selected.

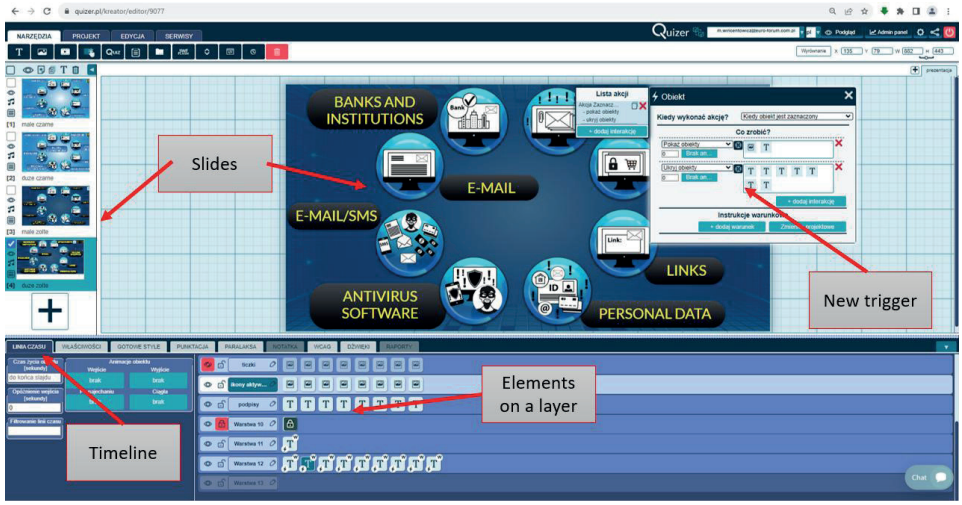

Figure 2. View of arranging textual and graphical elements on layers on the timeline and adding a trigger

S o u r c e: Own work.

Another element used during the creation of quizzes was a component that allowed for examining the contrast of the designed content. The component compares the colors of text and background using color codes in the RGB and HEX formats. By comparing the color combinations, the program returns the contrast value for WCAG AA standards for large and normal text, as well as WCAG AAA standards for large and normal text. Achieving an appropriate contrast ratio between the text and the background resulted in feedback in the form of green highlighting for a given standard. If the contrast criteria were not met, the "tile" with that standard would be highlighted in red. Figure 3a illustrates a comparison of yellow text color against a black background. The green tiles shown indicate that the contrast indicators are met for all four text standards. In Figure 3b, a less contrasting color combination of text and background was used (white text on a blue background). In this case, feedback was received about a too low contrast ratio. Only one out of the four standards is met - such a color combination is acceptable only for the WCAG AA standard for large text. By analyzing individual color combinations and adhering to the obtained results, those preparing exercises adapted to the needs of people with disabilities are able to create projects that meet specific WCAG guidelines and allow visually impaired individuals to fully benefit from such prepared resources. According to the WCAG standard, the minimum required contrast ratio (AA level) is 4.5:1 for regular text and 3:1 for text in the form of headings. The recommended contrast ratio for maximum contrast (AAA level) is 7:1 for regular text and 4.5:1 for text with a high level of enlargement. The presented content can be considered visually friendly and accessible if the contrast reaches at least the minimum level

(AA). An important principle applied in the design of web content (including e-learning) is that color should not be the sole means of conveying information. Users should also have the ability to change the font size of displayed information.

When starting the quiz, each user had the option to choose between a standard course or a course designed according to WCAG guidelines. The quiz could be solved using a mouse (basic version), keyboard and screen reader (WCAG version), or in a mixed system. While solving the quiz with a mouse, the user clicks on the answers, which change their state to selected. In case of changing the decision, by clicking on another answer, the previous selection is automatically removed. In the case of a correct answer, the user receives visual and auditory feedback, and user points are added to the course.

When solving the exercise using the keyboard and screen reader, the user receives information at the beginning that the quiz is adapted for people with disabilities and listens to the task instruction. Then, using the TAB key, the user navigates between the answers and selects one by pressing the spacebar. The selection field changes its state, and the user hears the information from the screen reader. In case of changing the decision, the user clicks the spacebar on another answer, which changes its state to selected and removes the previous selection. After providing the correct answer, the user receives visual and auditory feedback and is awarded points. In the case of an incorrect answer, the user also receives visual and auditory feedback indicating an incorrect response.

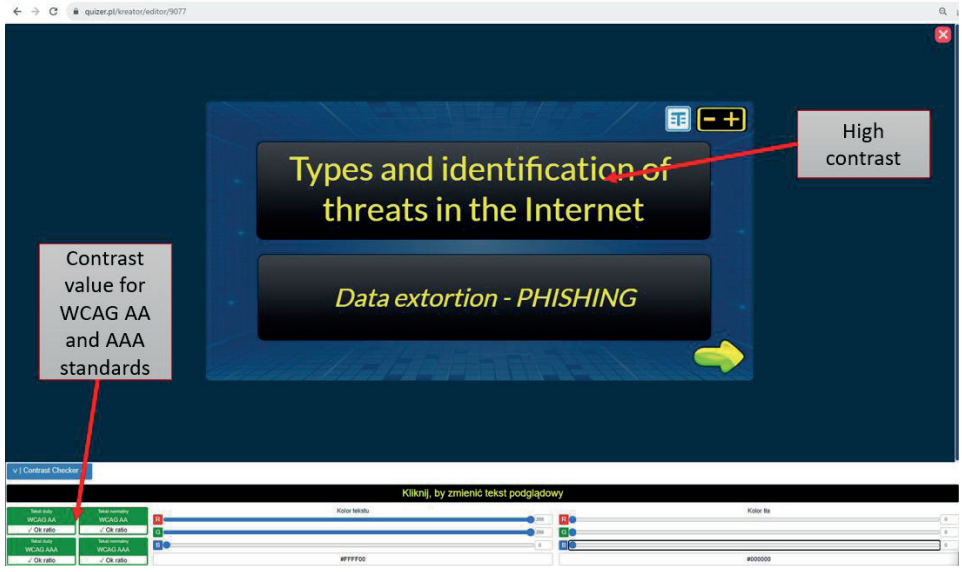

Figure 3a. Example contrast evaluation windows for the designed quiz: high contrast

S o u r c e: Own work.

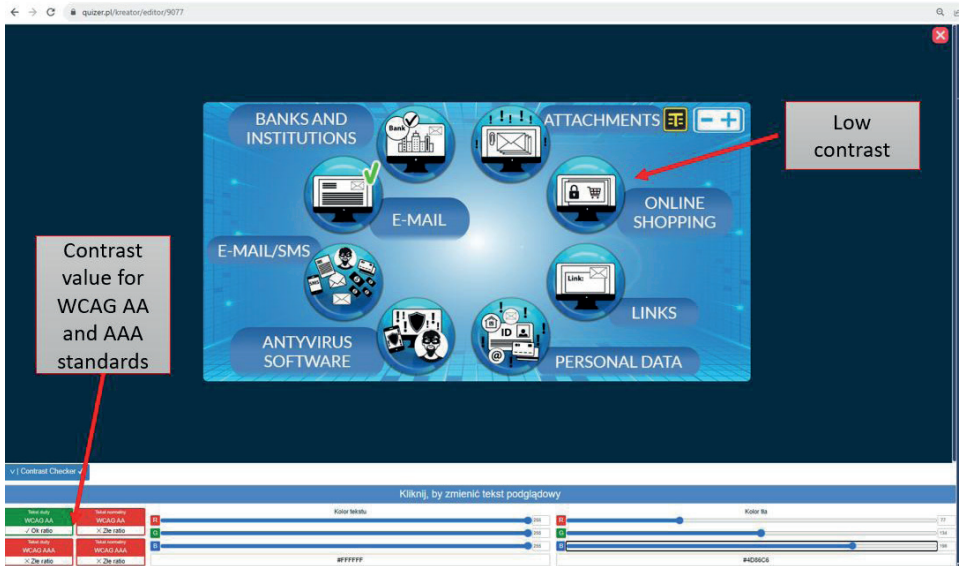

Figure 3b. Example contrast evaluation windows for the designed quiz: low contrast

S o u r c e: Own work.

User Research Methodology for E-Learning Quizzes

The conducted research consisted of verification of the correctness of implementing the WCAG component into the Quizer e-learning platform. The research was carried out in accordance with research ethics principles, involving two groups of individuals: (i) individuals with actual visual impairments and (ii) individuals with simulated visual dysfunction (blind individuals). Simulations of visual impairments were achieved by covering the eyes with a blindfold. The users also utilized headphones to eliminate the influence of the environment on the accurate understanding of the text read by the screen reader. The p articipants were provided with information about the research purpose and the procedure was explained to them. Access to the quizzes (presentation and test) was provided online through a web browser. In the first stage, participants were tasked with familiarizing themselves with the presentation and then completing the test. The test concluded with providing information about the achieved score of correct answers, presented as a percentage. It was assumed that for adult individuals, the time to complete one quiz should not exceed 5 minutes (300 seconds).

After completing the quizzes, the users answered questions in an electronic survey. The survey employed a five-point Likert scale, where: 1-Strongly disagree, 5-Strongly agree. Pilot (survey) studies were conducted with a group of 73 students majoring in Computer Science, aged 20-22, who were all students from Poland. These

students came from both rural and urban backgrounds. The majority of these individuals had already planned to pursue a degree in computer science during their primary school years. While attending university, they utilize an e-learning platform, although it is not compliant with WCAG (Web Content Accessibility Guidelines) standards. The studies were quantitative in nature and conducted in groups of 5 individuals within a dedicated computer laboratory. The tests utilized a standard QWERTY keyboard commonly found in laptops and desktop computers in Poland. The focus was on ensuring that the adaptation of web content for individuals with disabilities had broad applicability and did not require specialized equipment for operation. This solution allows people with disabilities to access online resources regardless of their access to specialized and often costly solutions. The screen reader presented the quiz user with audio feedback based on the acquired information. Screen readers are a form of assistive technology used by individuals who are blind, visually impaired, or have learning difficulties. The NVDA (NonVisual Desktop Access) screen reader was used for the tests. This tool was chosen for its low hardware requirements (minimum 1GHz processor speed, 256 MB RAM, and 90 MB storage space for smooth operation), which do not significantly burden the computer's performance, especially older models. Additionally, this screen reader is freely available, ensuring unlimited access for all users. To facilitate text perception in courses, the ability to change font size was also provided through a dedicated button. At the start of the quiz, users had the option to choose between a version without high contrast and a version with contrast enabled.

In order to compare the final results of quizzes compliant with WCAG (for students with disabilities) with the results of quizzes not adapted to WCAG standards (for students without disabilities), a study was conducted on a group of 73 students using the same quizzes, but without taking into account the WCAG guidelines. Pearson linear correlation coefficient was calculated for the survey data.

Results and discussion

Survey Results

The prepared survey, which was completed by the participants, was divided into two parts. The first part consisted of questions intended only for individuals with simulated visual impairment (blind individuals), while the second part contained questions for individuals with actual visual impairments. In the study with simulated visual impairment, 59 males and 14 females participated, while in the study with actual visual impairments, there were 14 males and 2 females. These individuals had visual impairments ranging from –2 to –6 dioptres and astigmatism. The survey included the questions presented in Table 1.

Table 2
Research Questions Included in the Survey

No.	The content of the question
	Part I
Q1.1	Was the voice information regarding navigation provided in a clear manner upon launching the quiz and throughout its duration?
Q1.2	Does the use of a keyboard enable navigation through the designed e-learning courses?
Q1.3	Does the screen reader recognize and interpret the elements of the e-learning course displayed on the computer monitor?
Q1.4	Does the applied screen reader correctly pronounce the content within the quiz?
Q1.5	Is there any repetitive content causing the screen reader to stutter?
	Part II
Q2.1	Is it clear which element is active during the navigation?
Q2.2	Did the contrast change improve the visibility of displayed content?
Q2.3	Did you notice an improvement in text quality after changing the font size?

The results of the survey, after answering the research questions, are presented in Figures 4–6. Figures 4–5 show the results for the first research group, which includes individuals with simulated visual impairment (blind individuals). Figure 7, on the other hand, represents the second research group consisting of individuals with actual visual impairment.

Figure 4 presents the results of responses to questions Q1.1 and Q1.2. In the case of the response to question Q1.1, over 75% of users expressed a positive opinion regarding the comprehensibility of voice instructions related to quiz navigation. 18% of users had no opinion ("hard to say"), and only 5% responded "probably not." Navigating through the designed e-learning courses using a keyboard (Q1.2) received very high ratings.

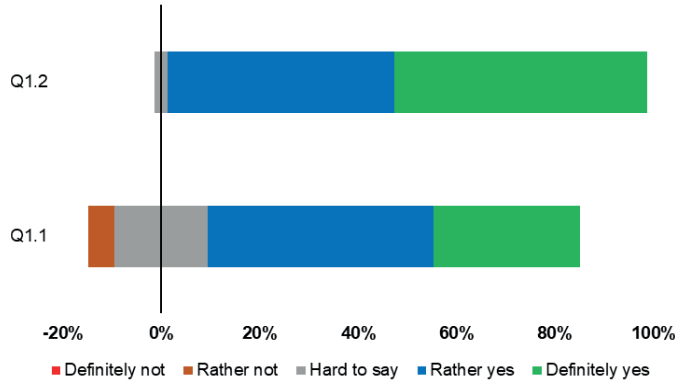

Figure 4. Results of responses to questions Q1.1 and Q1.2

S o u r c e: Own work.

The vast majority, over 97% of the test participants, had no difficulty navigating the quiz using a keyboard. They responded with "definitely yes" (51%) and "probably yes" (46%). Only 2 individuals responded with "hard to say." There were no negative responses. Figure 5 presents the results of the survey regarding the used screen reader (questions Q1.3, Q1.4, Q1.5).

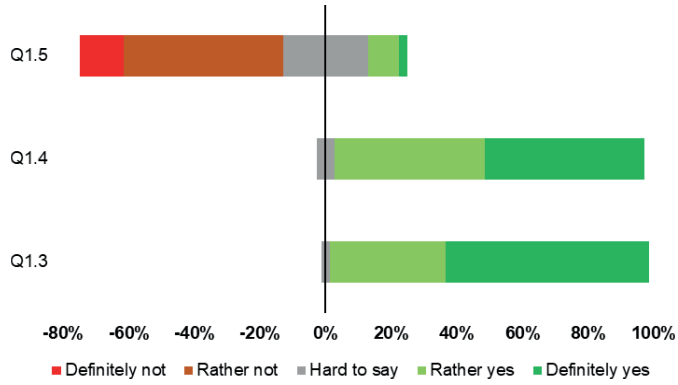

Figure 5. Results of responses to questions Q1.3, Q1.4, and Q1.5

Source: Own work.

The responses to the question "Does the screen reader recognize and interpret the elements of the e-learning course displayed on the computer screen?" (Q1.3) and "Does the applied screen reader pronounce the content in the quiz correctly?" (Q1.4) are very promising as they confirm the adequacy of adapting the e-learning course content to the screen reader used. Over 62% (Q1.3) and 48% (Q1.4) of users responded "definitely yes," while "rather yes" accounted for over 35% (Q1.3) and 45% (Q1.4) of responses. The correlation between the survey questions Q1.1–Q1.4 is moderate (changes from 0.39 to 0.48). In the case of question Q1.5, "rather no" responses were positive, while "rather yes" responses were negative (completely opposite to the previous questions). Over 62% of responses were positive ("definitely no" – over 13%, "rather no" – over 48%). Over 25% of responses were neutral – "hard to say," while only 12% were negative.

The results of the survey regarding the second group of test participants (individuals with actual visual impairments) are shown in Figure 6. In the case of question Q2.1 (Can you see which element is active during navigation?), over 56% of responses were positive, and 25% were neutral. Only 2 individuals answered "rather no," and 1 person answered "definitely no." The impact of contrast change on improving the perception of displayed content was also highly rated, with over 68% of users responding positively. Similarly, 2 individuals had no opinion. The negative responses were distributed in the same way as in question Q2.1. Changing the font size has a significant impact on improving the quality of displayed text (Q2.3), as confirmed by 94% of individuals with actual visual impairments.

The correlation between the survey questions Q2.1–Q2.3 is strong (changes from 0.56 to 0.82).

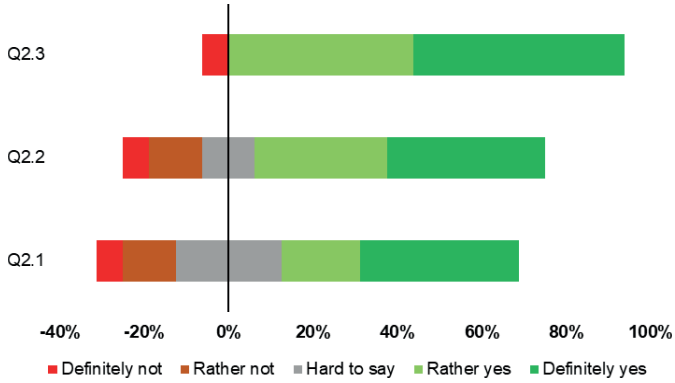

Figure 6. Results of responses to questions Q2.1, Q2.2, and Q2.3

S o u r c e: Own work.

The final results of the quiz prepared according to the WCAG guidelines were compared with the results of people using the standard quiz without WCAG, as shown in Figure 7.

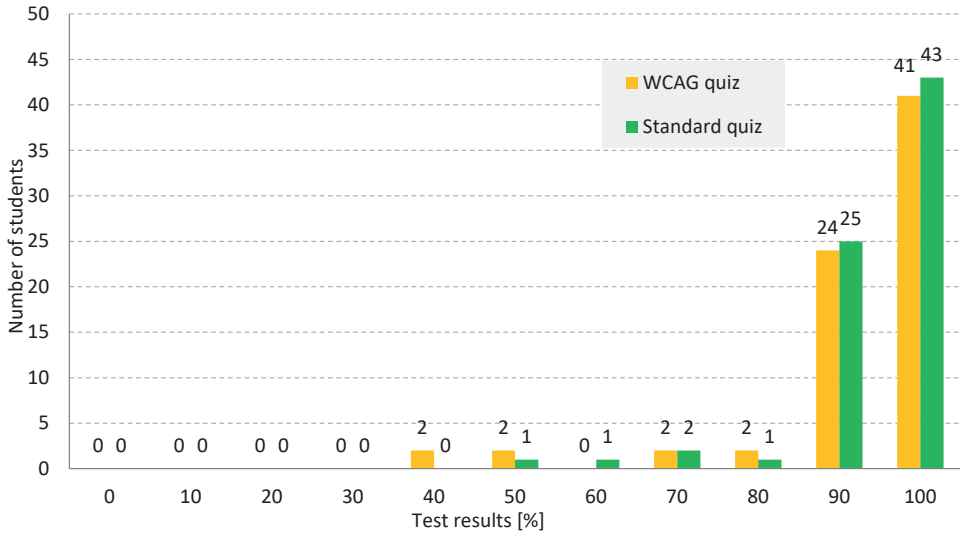

Figure 7. Quiz results

S o u r c e: Own work.

For the quiz with WCAG, the results obtained were quite high, comparable to the results for the standard quiz. This confirms the correct development of the

course and the operation of the WCAG tools used both in the presentation and in the quiz test. More than half of users scored 100% for this type of quiz. Other results are as follows: over thirty percent of users received 90%, 2 people – 80%, 2 people – 70%, 2 people – 50% and 2 people – 40%. All users completed the quizzes within the set time (less than 5 minutes). The average score for the WCAG quiz was 92% and for the standard quiz 94.24%. This is a very similar result, confirming the possibility of equalizing opportunities in access to the quiz and obtaining a positive result for people with disabilities. The correlation between the survey questions and quiz results is weak (below 0.3).

Determination of guidelines for preparing e-learning courses that comply with WCAG standards

Taking into account the specific needs of visually impaired individuals who may have difficulty or limited ability to track mouse movement on a computer screen, it is necessary to implement solutions that can overcome these obstacles. Analyzing the results of the tests, it can be concluded that the use of an e-learning platform, including interactive exercises, with the use of a keyboard and screen reader, is a suitable solution for visually impaired individuals. By employing such a solution, these individuals can navigate and perform specific actions in the course using designated keys and keyboard shortcuts (e.g., the Tab key). Clear highlighting of the active element allows visually impaired individuals to determine their current location within the resource. Additionally, by utilizing screen reader tools, individuals who are completely blind can also access such resources. Keyboard navigation enables logical, pre-planned, and defined movement on the screen, while the screen reader informs these individuals about their current location, available content, and possible actions. Interactive content, where user actions have visual effects (e.g., choosing different paths in an exercise), often presents difficulties or renders the resources completely unusable for individuals with visual impairments. A proper preparation of web resources, including interactive exercises, offers the opportunity to minimize barriers for people with disabilities in accessing these resources. By using keyboard navigation and a screen reader, it is possible to create exercises in which users can follow a planned path, respond to received instructions, or perform required actions. The feedback provided after answering a question or completing a task allows users to proceed to the next stages of the exercise or improve their responses. Through a thoughtful planning and preparation of interactive exercises, barriers to accessing these resources for individuals with disabilities can be significantly reduced without compromising the visual and interactive aspects for able-bodied individuals. In summary, the developed component enables a higher level of compliance with WCAG guidelines for multimedia educational content, strengthening access to education for individuals with disabilities, including visual

and hearing impairments. After conducting the research, general guidelines were formulated for the proper construction and development of e-learning exercises in accordance with WCAG guidelines. It was determined which elements should be visible upon opening the project, what the logical task execution and feedback presentation paths should be, and what actionable options are necessary from the keyboard and screen reader perspective. These guidelines can serve as a framework for designing quizzes for individuals with limited access to digital educational content.

The key assumptions for the WCAG component are as follows:

1. The screen reader only perceives elements that have the visibility option enabled. Other elements are invisible to the screen reader. This allows for planning the user's task execution path by controlling what and in what order the user will see or hear.
2. The screen reader only perceives elements that are active and visible on the timeline. Even elements with the visibility option enabled for the screen reader must remain invisible to the reader until they are shown on the timeline in the Creator tool. This solution enables determining the moment when specific options become available to the user, taking into account the stage of the exercise at which the user is currently.
3. Each element with the visibility option enabled for the screen reader must have an alternative text filled in. The alternative text must not contain words written with spaced-out letters.
4. When a specific element is selected, the screen reader automatically reads its associated alternative text. This event does not require any action from the user.
5. Pressing a designated key allows for moving to the next element. According to the WCAG standard, moving to the next element is done using the TAB key.
6. A designated key combination allows for returning to the previous element with the visibility option enabled for the screen reader. According to the standard, the Shift+TAB key combination is used for this purpose. In accordance with the previous assumptions, the selection will return to the previously visited element unless it has been hidden on the timeline. In such a case, the selection will stop at the first visible element on the timeline.
7. The order of navigating between elements is determined by their arrangement on the timeline: the screen reader cursor moves through marked and visible elements from left to right, from the top layer to the bottom. If there is only one element on consecutive layers, the selection moves through the layers from top to bottom while adhering to the visibility criterion for the screen reader and the timeline.
8. The 'space' or 'enter' key allows for replicating the functionality of clicking the respective element on the screen.
9. Pressing the 'space' or 'enter' key on a selected element enables executable actions, similar to objects operated by the mouse. This allows users with disabilities to access all the executable actions available in the Creator tool, includ-

ing showing objects, hiding objects, displaying layers, hiding layers, moving to the next, previous, or any chosen page, playing, pausing, or stopping audio recordings, changing the value of a score or user variable, altering the style of elements, managing the timer, checking individual exercises, or all exercises in the course, as well as handling video files.

10. Selecting an element visible to the screen reader provides executable actions similar to the event of hovering the mouse over an object. The available actions for the event of selecting an element are the same as those for clicking the mouse button.
11. Upon opening the project, the screen reader selection automatically sets to the first visible element with the WCAG component enabled. This allows screen reader users to orient themselves within the course upon project loading and provides instructions on further steps to solve the exercise.
12. Upon page loading, the screen reader automatically reads the alternative text from the first visible element. This event does not require any user intervention. It provides an opportunity to present the user with the exercise procedure and instruct them on the tasks involved in a specific exercise.
13. Every change on the screen must be initiated by user action. The a utomatic appearance and disappearance of elements should be eliminated. This approach avoids the confusion that could arise when things happen automatically in an exercise for which the user is not prepared. It can also distract the user and make the technical execution of the task more difficult.
14. The elements selected by the screen reader must be clearly marked with borders/highlighting, according to the standard. The visibility of focus should be maintained. This provides additional support for visually impaired individuals when solving the task. The border should be adjusted to the content of the task in terms of contrast.
15. A sufficient contrast must be ensured between the elements present on the page and the background. According to WCAG guidelines, this parameter should be at least 4.5:1. In all cases where the color of an element is defined in the stylesheet, the background color on which it is placed is also defined.
16. The exercise must have a mechanism that allows the view on the page to be enlarged up to 200% while maintaining the visibility of all information.
17. The occurrence of a keyboard trap, where the user is unable to complete the task entirely using the keyboard, must be avoided. Points related to navigating between elements and executing actions on events allow for arranging elements and planning the logic of task solving to avoid such a situation.
18. The exercise and the page on which the exercise is located must not have an automatic refresh mechanism. Such a mechanism prevents the completion of the exercise, leading to loss of focus and the need to start the task-solving process from the beginning. There should also be no mechanism in the exercise or on the page that automatically redirects the user to another address.

Conclusions

The present article raises the key issue of making digital educational content available to people with disabilities, in particular those with a visual impairment. The main objectives of the study were to develop an interactive creator of exercises in accordance with the WCAG 2.1 guidelines and to assess the effectiveness of its implementation on the Quizer e-learning platform. On the basis of tests and user studies, the following final conclusions were formulated:

1. The study showed that a customized e-learning platform successfully enabled people with visual impairments to navigate and interact with a keyboard and a screen reader. The respondents reported clear and understandable voice instructions for navigation, and keyboard interaction provided intuitive navigation paths.
2. It was found that the screen reader used (NVDA) effectively recognizes and interprets elements of e-learning content displayed on a computer screen. It correctly pronounced the content included in the quizzes, increasing the accessibility of educational materials for users with visual impairments.
3. The introduction of the contrast adjustment option had a positive impact on the visibility of the displayed content, thus improving the reception of educational materials by visually impaired users. They noticed improved text quality after changing the font size, further highlighting the importance of customization for accessibility.
4. The study compared the results of quizzes developed according to WCAG guidelines with standard quizzes. The results showed that the WCAG-adapted quizzes achieved a similar success rate to the standard quizzes, highlighting the effectiveness of the adaptation in providing equal educational opportunities for people with disabilities.
5. The obtained results led to the formulation of guidelines for the design and development of accessible e-learning exercises in accordance with the WCAG guidelines. These guidelines emphasize elements such as keyboard navigation, screen reader compatibility, contrast adjustment and logical task paths to ensure accessibility without compromising the interactive aspects.

The results of this study have important implications for the field of inclusive education and e-learning. The successful integration of WCAG guidelines into an e-learning platform, along with positive feedback from users with visual impairments, demonstrates the feasibility of creating digital learning resources that meet a variety of accessibility needs. To sum up, the research has shown that adapting e-learning exercises to the WCAG 2.1 guidelines significantly improves accessibility for people with disabilities, especially those with visual impairments.

The study provides valuable information on the implementation of accessibility features, highlights their positive impact on user experience and educational

outcomes, and establishes guidelines for the design of accessible e-learning materials. By prioritize accessibility, educational institutions and content creators can help create an inclusive learning environment that benefits all students, regardless of their ability.

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Krzysztof Dziedzic, Marcin Barszcz, Tomasz Wiśniewski

Dostosowanie kreatora ćwiczeń e-learningowych do potrzeb osób z niepełnosprawnościami utrudniającymi dostęp do edukacji

S t r e s z c z e n i e

Niniejszy artykuł dotyczy implementacji wytycznych WCAG 2.1 w kursach elearningowych. Bazą do wprowadzenia komponentu WCAG była platforma elearningowa Quizer, umożliwiająca tworzenie interaktywnych kursów multimedialnych. W skład platformy wchodzą dwa podstawowe narzędzia: kreator ćwiczeń i prezenter ćwiczeń.

Po przeprowadzeniu analizy kreatora ćwiczeń na platformie Quizer, opracowano koncepcję kursów i zaimplementowano komponent umożliwiający tworzenie kursów e-learningowych zgodnych z wytycznymi WCAG 2.1 i przeznaczonych dla osób z niepełnosprawnościami. Zaprezentowano również technologię wykonania tego komponentu. Omówiono także funkcję i zasadność poruszania się po kursach z wykorzystaniem klawiatury oraz przedstawiono zastosowanie czytników ekranu.

Badania dotyczące poprawności implementacji standardu WCAG 2.1 w kursach elearningowych były przeprowadzane z użyciem quizów z zakresu cyberbezpieczeństwa. Porównano również wyniki końcowe quizów przygotowanych według wytycznych WCAG i bez WCAG. W badaniach wzięli udział studenci kierunku informatyka Politechnik Lubelskiej. Wyniki badań wskazują na zasadność stosowania wytycznych WCAG w projektowaniu treści edukacyjnych dla studentów z niepełnosprawnościami w celu wyrównania ich szans edukacyjnych.

S ł o w a k l u c z o w e: e-learning, kreator ćwiczeń, kursy multimedialne, WCAG 2.1

Krzysztof Dziedzic, Marcin Barszcz, Tomasz Wisniewski

Adaptar el creador de los ejercicios e-learning a las necesidades de las personas con discapacidad con difícil acceso a la educación

R e s u m e n

Este artículo se refiere a la implementación de las pautas WCAG (Web Content Accessibility Guidelines) 2.1 en los cursos de aprendizaje electrónico. La base para la introducción del componente WCAG fue la plataforma de e-learning Quizer que permite la creación de cursos multimedia interactivos. La plataforma consta de dos herramientas básicas: creador de ejercicios y presentador de ejercicios.

Después de analizar el creador de ejercicios en la plataforma Quizer, se desarrolló un concepto y se implementó un componente para permitir la creación de cursos de aprendizaje electrónico de acuerdo con las pautas de WCAG y dedicados a las personas con discapacidad. También se presentó la tecnología de creación de este componente. Igualmente se discutió la función y la conveniencia de navegar por los cursos usando el teclado así que el uso de lectores de pantalla.

La investigación sobre la corrección de la implementación del estándar WCAG en los cursos de aprendizaje electrónico se llevó a cabo con el uso de pruebas de ciberseguridad. Los estudiantes de Informática de la Universidad Tecnológica de Lublin participaron en el estudio. Los resultados de la investigación indican la conveniencia del uso de las pautas WCAG en el diseño del contenido educativo para los estudiantes con discapacidades y el igualamiento de las oportunidades educativas.

P a l a b r a s c l a v e: e-learning, creador de ejercicios, cursos multimedia, WCAG

Кшиштоф Дзедзис, Марцин Барщ, Томаш Вишневски

Адаптация креатора упражнений электронного обучения к потребностям людей с ограниченными возможностями с затрудненным доступом к образованию

Аннотация

Эта статья касается реализации рекомендаций WCAG (Web Content Accessibility Guidelines) 2.1 в курсах электронного обучения. Основой для внедрения компонента WCAG стала платформа электронного обучения Quizer, позволяющая создавать интерактивные мультимедийные курсы. Платформа состоит из двух основных инструментов: создания упражнений и представления упражнений.

После анализа Конструктора упражнений на платформе Quizer была разработана концепция и реализован компонент, позволяющий создавать курсы электронного обучения в соответствии с рекомендациями WCAG и предназначенные для людей с ограниченными возможностями. Также была представлена технология изготовления этого компонента. Также обсуждаются функции и правомерность навигации по курсам с помощью клавиатуры и использования программ чтения с экрана.

Исследование правильности реализации стандарта WCAG в электронных учебных курсах проводилось с использованием разработанных тестов в области кибербезопасности. Были сравнены также окончательные результаты тестов, приготовленных в соответствии с рекомендациями WCAG и без WCAG. В исследовании приняли участие студенты факультета информатики Люблинского политехнического университета. Результаты исследования свидетельствуют о правомерности использования рекомендаций WCAG при разработке образовательного контента для студентов.

Ключевые слова: электронное обучение, создание упражнений, мультимедийные курсы, WCAG