Accessibility of E-Learning and STEM Education

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Abstract **– Conducted research shows lower achievements of pupils and students in subjects with a STEM focus. This study explores the inaccessible educational environment and the possibilities of providing web accessible learning resources. The goal is to develop a methodology for creating an accessible educational resource in STEM disciplines and opportunities for personalization. Surveys, statistical analysis, building and evaluating a model with customized components were used as research methods. The stages of the research include exploring the issues, identifying barriers to learning for people with disabilities, exploring practical solutions and common standards, as well as implementing an accessibility web portal. The results showed inadequate knowledge of the problems in the education of people with different disabilities on the part of teachers. On the other hand, the study of principles and standards led to the development of accessible web resources and a system of requirements for them. The created learning web portal can be used by teachers, students and pupils to achieve higher results and improve satisfaction after interacting with the learning site.**

Keywords **– Accessibility, STEM education, programming, students with disabilities.**

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1. Introduction

For a long time, students with disabilities have been perceived as not as capable of academic achievement unlike others, students without disabilities [1]. The reason can be found in the dominant medical model of disability. In recent years, the social model is changing the view towards the barriers placed by the environment. The practice proves that if they are given the proper accommodations that allow the success, they can be no less successful than their classmates [2], [3], [4].

Repulsion of students with disabilities from a certain subject starts at the elementary school level. They tend to be tracked way from pursuing advanced academic endeavours. The achievements of the students in the institutions in subjects with STEM orientation are at a lower level due to the higher requirements and the higher workload. Thus, these students do not meet the criteria, and this is an unfavourable assessment of the schools.

The advice on this trend is to "hide" from general education and to separate into special classrooms, to focus on different programs or alternative schools. The reason for this could be found in the financing of schools based on standardized assessments [5].

Research shows that 10% of students starting college identify as having a disability, but fewer are in advanced courses during high school and college. Students with disabilities represent about 12% of high schoolers, yet only 1% is in advanced classes.

Further studies reveal that while these students earn the same English credits as others, they earn significantly fewer in math and science. This can lead to the belief that they are not as capable, especially in STEM areas, making them feel less qualified and trapping them in a cycle of low expectations and poor performance. Additional problems can arise if the students begin to believe that their grades depend on the instructor's opinion of their abilities [6].

Students who believe they are not "supposed" to do well tend not to. This can be described as low self-esteem or "expectancy effect". The results are lower performance on tests, losing interest in STEM educational methods, and declining desire and efforts to refute biases. Most studies highlight on problems with different minorities groups in STEM fields [7], but to assume the similar damaging projection on students with disabilities would be illogical [8], [9], [10], [11].

In the last two decades, there has been a decline in research focused on the disability status of students in higher education, raising important concerns about how well the challenges these students face are recognized [12]. The gap between the academic acknowledgment of disabilities and their actual prevalence points to significant issues in understanding their needs. Additionally, much of the research tends to lump all students together, failing to differentiate between those with cognitive or learning disabilities and those with other kinds. This lack of distinction can miss critical details and impede the development of effective interventions tailored to various disability types.

The rate of unemployment is extremely high among people with disabilities – only about 35% are employed. This underscores the lack of specific support for disabled teachers and highlights the critical need to address their needs in the field of education [13].

Some researchers argue that educators often lack the ability, readiness, or adequate preparation to identify and cater to the requirements of students with disabilities. Consequently, the course material may become inaccessible [14], [15]. If students do not have access to STEM workflow, they become unnoticed. This leads to constant absence of students with disabilities in STEM fields. It is important to identify the obstacles they encounter, particularly in STEM classes [15].

A small number of them in postsecondary education tend to openly admit their disability. Most choose not to disclose due to the stigma involved. Considering the lack of accurate data on disabled students and the overall obscurity of this issue, it turns into a critical concern [1]. And that is not all. Barriers are even more serious at the workplace. Researchers, instructors, professors with disabilities in institutes, universities, colleges in STEM are underrepresented [16].

2. Analysis and a Case Study of Accessibility Problems in Educational Process

Despite the fact that there are a lot of intentional helpful projects, inaccessible educational environment, learning resources, activities, etc., present serious barriers to students with disabilities [17].

The previous pandemic years proved that digital inclusion is an important topic in every aspect of life, especially in education. Problems exist not only for students, but also for teachers and lecturers, researchers, and more [18]. For months students had to participate in school activities remotely from their homes using digital technologies. In many cases they were not accessible. There were problems with the software for remote conferencing, LMS inaccessibility, inaccessible resources like books, documents, videos, graphical content etc. Many case studies describe such problems and suggest solutions [19].

The lack of information about people with disabilities and their real needs is one of the reasons for the poor state of accessibility in areas such as education and realization of individuals in this group.

In 2020 in Bulgaria a survey on the awareness of teachers was published in 12 schools. The survey focuses on two key areas:

- To establish the level of awareness of teachers about the specific problems and the need for accessibility of students with disabilities in the educational process
- To register the observations and attitudes of the teachers regarding the students with disabilities and their achievements.

It turns out that 75% of teachers have met students with disabilities in their practice. Only 38% of respondents declare adequate preparation for working with students with disabilities. Of these, the largest share is of those trained work in the humanities (55%), followed by teachers with technical expertise (27%), and the least prepared are in the field of natural sciences - 18%.

Table 1. Distribution of the attitudes regarding the information for work with students with disabilities by scientific directions

	Natural Sciences	Technical	Humanities
Declaring adequate preparation	18%	27%	55%
Have no information but looking personal contact	33%	33%	33%
Seeking additional information	0%	67%	33%

Unfortunately, the youngest professionals do not have a representative to declare adequate training to work with students with disabilities. Continuing the study of the set of respondents who answered positively to the question of whether they provide distance learning, some interesting relationships are found, set out in the Table 2.

Table 2. Comparison of answers for distance learning availability

Distance Learning Availability	Website Accessibility	Accessibility Audit
Yes	45%	5%
No	10%	15%
I am Not Aware	45%	80%

The data shows that almost half of those whose schools offer distance learning believe that the site or the LMS used is accessible. However, this is due to subjective belief, as when asked whether a real audit was conducted, only 5% answered in the affirmative. Only 10% are convinced that the school's website is inaccessible, and the remaining 45% cannot answer.

The share of those who are convinced that an audit of the accessibility of the website has not been performed is higher. The share of those who could not give a specific answer is almost double, which could be interpreted as uncertainty and unawareness.

The supporters of the version for the conducted accessibility audit are from a single educational institution. They indicate an average level of accessibility. But even this confidence is shared by a small number of teachers, as 17% say yes, as many say no, and the other 2/3 cannot give a specific answer.

3. Recommendations for Web Accessibility

On the positive side, learning remotely in post-secondary education has the potential to eliminate some challenging factors such as time and distance which can be a serious barrier to students with disabilities. But to really be on the positive side, the entire online process, realized by the learning platform with its interface and content with all communication channels, examination process etc., must be accessible.

According to the ISO 9241-171 standard the accessibility is the usability of any type of end user product by the users with different types of potentials. It goes beyond usability for people with recognized disability [20].

The Office for Civil Rights in the U.S. defines "accessible" as ensuring that individuals with disabilities have the same chance to access information and benefit from services. While the experience may not be the same, the technology must still offer equal access to educational resources.

This means that the learning process, resources, and experience must be adapted to the user's needs and abilities, including the proper assistive technologies.

Regarding web-based education there are international standards released by W3C that can be applied to the content and the interface of the learning platforms used whether they are offered as ready-made or custom-built solutions. WCAG 2.1 is widely accepted and adopted by European Union, US, Canada, UK, Australia, and other countries [21]. The European standard EN 301 549 is based primarily on WCAG 2.1 [22]. The guidelines are applicable to a wide range of products – websites, documents, desktop and mobile apps and other interfaces.

Since students in distance learning courses may come from a different background, have variety of personal characteristics and learning styles, one or more disabilities, the e-learning systems used in education must be designed with universal access in mind. No designer can preliminarily know what characteristics each user of the system has. Universal design is described as creating products and environments that can be fully used by everyone possible, without requiring modifications [22]. This means that universal design is accessible design.

Unfortunately, in many cases creators of distance courses think about accommodations for people with disabilities after such person enrols in the course instead of making it accessible from the start. Thinking about accessibility from the design stage is cheaper, takes less time and improves the learning experience for all students. On the contrary, inaccessible platform and content can seriously hinder or severely restrict participation.

According WCAG 2.1 the web content and interface are accessible if they are subject to the following four principles on which the standard is built: perceivable, operable, understandable, and robust [21]. Each principle contains a few guidelines that summarise various aspects of accessibility. Under each of the thirteen guidelines are the so called "success criteria" (SC). Each of them is constructed as a testable statement to determine if content is accessible or not. All criteria are categorized into three levels to meet diverse needs and situations. "A" level is the lowest possible level but is not enough to cover broad groups and situations. The "AA" level is the recommended level of conformance for all websites. The SC from the highest "AAA" level are impossible to meet for all content at once so it is not required. Nevertheless, authors and developers are encouraged to meet as many of these criteria as possible to achieve greater accessibility.

Conforming to a particular level means the website conforms to all lower levels. In other words, by conforming to "AA", a Web page satisfies all applicable SC on both the "A" and "AA" conformance levels [20], [21], [22].

In short, all this means that the content and interface of the e-learning platforms used must not present barriers before students and lecturers with different abilities and needs. They must have equal opportunities and experience as their counterparts without disability. In general, the main problematic areas can be perception, navigation, orientation, operation, clear identification, visibility, readability, input and interaction, consistent and logical order.

Keyboard

Navigation and operation from a keyboard or other alternative input device is important for people who have difficulties using a mouse or for keyboard only users. Therefore, all interactive elements must be reachable from the keyboard. The focus should not be trapped in a loop (except modal dialogs). The cursor must not be stuck on an element. Positioning on an element must not cause an unexpected or unwanted interaction or change of content or context [21]. No time to accomplish a task (except examination). Even then there should be some allowance considering specific disabilities.

Logical Focus Order and Reading Order

The user must always see and follow the cursor position . The focus must be visible all the time, the focus order and the reading order must be logical. There must be no difference in the logic in the content of interface for sighted and visually impaired users.

Multimedia and Non-Text Content

All essential non-text information must be presented in an alternative format without losing meaning. “Non-text” may include charts, schemes, images, pictures, photos, and other graphical content. Their meaning should always be presented in an alternative way that equally describes the content so a visually impaired person can understand the meaning. This is usually done as electronic text. No images of text should be used with few exceptions.

Audio must have a transcript as an alternative. Videos must have captions (subtitles), audio description and transcripts.

Multimedia must not play automatically, or it should have a straightforward way to mute, pause or stop it from the keyboard. All moving, blinking, and scrolling content needs a way to pause or stop.

No content or meaning is lost while zooming.

Colour

The good colour contrast is another important consideration for those who have low vision or are colour blind.

The requirements for contrast can be found in WCAG SC 1.4.1. Colour alone must not indicate essential information. There must be at least one more additional method of indication.

Structure and Semantics

The content must be structured by using semantic elements as landmarks, headings, lists and tables. All semantic elements must be used as intended in specifications.

It is good practice to consider starting the course with a section clarifying how to navigate the course. It should include the elements used, their positioning and the way to interact.

These are just a few basic examples of what must and must not be done.

4. Educational Web Portal for Students With Disabilities

As a summarizing result of the research and for the purpose of sustainability of the results, a specialized web portal about accessibility has been developed. The main goals and tasks of the research are presented in [23]. In this section, a development and capabilities of a web portal related to accessibility are presented. The site contains testing recommendations and creating accessible learning resources, specialized programming example tutorials, and a built-in test script for automated testing. Using some of the techniques discussed in [23], [24]. The PHP framework and JavaScript components were developed, and the entire site is based upon it and the accessible user components for visualization of the sample parts of the source code.

The web portal contains the following sections:

- **DIGITAL ACCESSIBILITY**
  Contains information about web accessibility essential and principles. Additional information like external links, documentation and video materials are also included.

- **WEB ACCESSIBILITY TESTING**
  - **Testing methodology –** steps of a testing methodology have been presented. These include principles related to development of accessibility: Alternative texts for images, Document structure, Tables, List Structure, Form Labelling, Hyperlinks, Keyboard Accessibility Testing, Colour contrast;
  - **Automated testing –** includes an overview of some popular automated accessibility testing tools and custom developed applications embedded in the site that could be used for generation of automated accessibility testing reports.

- **ACCESIBLE LEARNING MATERIALS**
  - **Development principles** – recommendations according to W3C and the WHATWG standards are presented, and templates of accessible learning resources are included.
  - **Involvement in the learning process -** analysis of possibilities for inclusion of research results in the teaching process for the bachelor's and master's programs is presented. A test adapted for people with visual impairments has been developed.
  - **Lessons –** an example organization of online accessible lessons is presented for three programming technologies (HTML, CSS, PHP).

The methodology formulated in the web portal for increasing the level of accessibility of learning resources includes the following principles:

- **TEXT RECOMMENDATIONS**
  - Add the option for bigger font size in a web page if desired by the visitor.
  - Set larger line spacing for longer paragraphs to make them easier to read for disabled users.
  - The colour selection should be with the proper contrast. The classic scheme of black letters on a white background (for text, cell, square, box, table, header and footer) is most comfortable for colour blind people.
  - Choosing appropriate fonts on a webpage can enhance readability. Fonts from Sans-serif family are more accessible and help easing the strain of reading.
  - No text in capital letters only, avoid italics and word underlining.
  - Text should be organized into smaller, prioritized sections to make it easier to be used while retaining the information.
- **MULTIMEDIA RECOMMENDATIONS**
  - Add to each image (and the other visual elements) descriptions by means of alternative text (via the alt attribute) or by caption (via the <figure> and <figcaption> tags).
  - It is recommended that the alt text conveys the content of the image and its purpose in one or two sentences.
  - The graphic elements in the menus should feature larger and high-contrast images along with explanatory text for better accessibility.
  - Descriptive text for a visual element should not repeat the text before and after the visual element.
  - Add subtitles to video and audio elements to facilitate hearing-impaired visitors.
  - Avoid using schemes with educational purposes because their text explanations are not able to represent relations between constituent components.
- **RECOMMENDATIONS FOR LINKS AND NAVIGATION**
  - Put more space before and after individual buttons and elements of the options tag.
  - The colour selection should provide sufficient contrast with the colour squares of the links.
  - Text of the link tags must be concise and explanatory.
  - Labels should give a clear idea of their direction independently of the other links in a menu.
  - Add an effective navigation system to the site – information about the current educational thematic together with the connections to similar lessons and look back on prior knowledge.
- **RECOMMENDATIONS FOR TABLES**
  - Tables should not be used for visual layout, but should only be used to present tabular data.
  - If tabular presentation is required, do not include merged cells because they make it difficult to read the content with a program.
  - Do not use nested table because the content is difficult for a program to read and for the visitor to understand.
  - Do not leave blank cells in a table because processing them by a screen reader can confuse visitors.
  - Add table column headings with <thead> and <th> tags because they make it easier to orient the visitor in the table data.
  - Do not use tables with fixed sizes, because they are difficult to read for people with impaired vision (through a magnifying glass or zooming in the browser).

The implementation of the accessibility principles in the standard learning process can take different forms:

- As part of lectures and workshop exercises, consider accessibility recommendations, accessibility tests and tools, examples of accessible web pages, and web design mistakes that cause difficulties for visually impaired people.

- For students to become familiar with accessibility standards and the activities of leading web technology organizations during lectures or as an independent work assignment.
- As tasks for practical independent work, implement elements on sites that are easy to use for visitors with impaired vision - for example, buttons with readability, colour schemes with good contrast, functionality to increase the font, etc.
- Within the framework of practical web design projects to provide work and assessment of accessibility.
- Add text-reading functionality to online exam tests and make their overall layout compliant with web content accessibility rules.
- To offer topics for bachelor's and master's theses that are related to the construction and administration of sites accessible to blind visitors.

In the example lessons included in the web portal is used a custom text area component to illustrate the source code in a more accessible way (Figure 1).

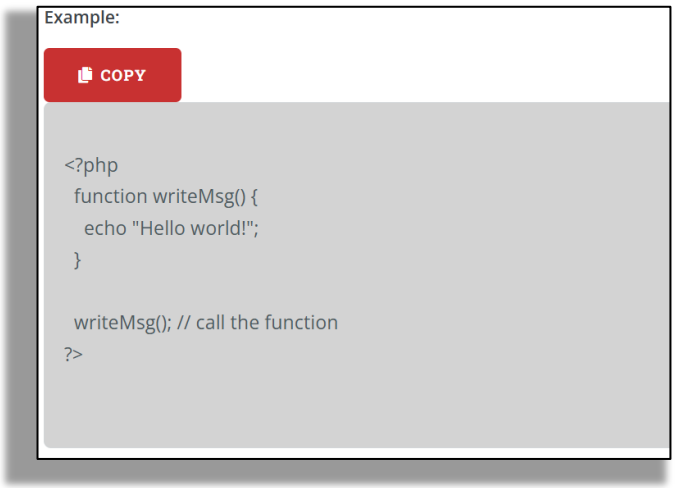

Figure 1. Accessible text area component

```
class AccessibleCode extends HTMLElement  {
    connectedCallback() {

        var audio = new Audio("soundfile.mp3");

        let txtLbl = document.createElement('label')
        txtLbl.setAttribute('for', 'lbl' +  this.id)
        txtLbl.innerText = this.getAttribute('lbltxt')

        let txtBtn = document.createElement('button')
        txtBtn.setAttribute('class', 'btncopy button primary icon solid fa fa-copy')
        txtBtn.setAttribute('data-clipboard-target', '#txtBox' + this.id)
        txtBtn.innerText = 'Copy'

        txtBtn.onclick = function() {
            audio.play();
        }

        let txtArea = document.createElement('textarea')
        txtArea.setAttribute('aria-readonly', 'true')
        txtArea.setAttribute('readonly', 'true')
        txtArea.setAttribute('style', 'background-color:lightgrey')
        txtArea.setAttribute('id', 'txtBox' + this.id)
        txtArea.setAttribute('rows', this.getAttribute('rows'));
        txtArea.setAttribute('aria-label', 'Code')
        txtArea.innerHTML = this.innerText;

        this.innerHTML = ''
        this.appendChild(txtLbl);
        this.appendChild(txtBtn);
        this.appendChild(txtArea);
    }
}
```

Figure 2. Accessible text area component – source code

The component is created using a custom class **AccessibleCode** (Figure 2) that inherits the standard web component class **HTMLElement.** In this way the developer could manipulate and customize the process of web element rendering. According to good web practices **connectedCallback()** method should be implemented with custom logic instead of the class constructor.

The custom accessible text area component contains three integrated web components – **label**, **button** and **text area.** In their rendering are used values from the parent component attribute – the **id** attribute is used to generate unique ids for child components, **rows** attribute to customize text area rows and **lbltxt** attribute for the text of the label component.

The main accessibility features that are incorporated in the component are:

- **WAI-ARIA** attributes - particularly useful when working with dynamic elements and more complicated design structures;
- **Audio** component – used to play a sound on **Copy button** click to notify the visually disabled users that the text from the text area is copied to the clipboard;
- Custom **Copy button** that stores the text area content into the clipboard so that the visually disabled users could use it in running examples. The button uses ClipboardJS library to customize the process of clipboard usage [25]. To initiate the library object the CSS class for the monitored object should be defined:

```
let clipboard = new ClipboardJS('.btncopy');
```

Next, the value of data-clipboard-target attribute of the button tag should be set to match the element selector of the copied element content – in this case the ID of the text area:

```
txtBtn.setAttribute('data-clipboard-target',
    '#txtBox' + this.id)
```

Figure 3 presents the source code of example usage of the custom accessible component.

```
<access-code id="HTMLCode1" rows="10" lbltxt="Example:">
<xmp>
  <!DOCTYPE html>
  <html>
    <body>
        <h1>New Products</h1>
        <p>Our <b>latest</b> products are ... </p>
    </body>
  </html>
  </xmp>
</access-code>
```

Figure 3. Example usage of the accessible component

The name of the custom tag is **<access-code>** and attributes **ID**, **rows** and **lbltxt** should be set to customize the component. The inner HTML code of the tag is used as a content of the generated text area.

A custom JavaScript component is developed to help visually impaired users to zoom in and out the web site content according to their needs. Figure 4 and Figure 5 show the visual presentation of web component and the JavaScript source code for its realization.

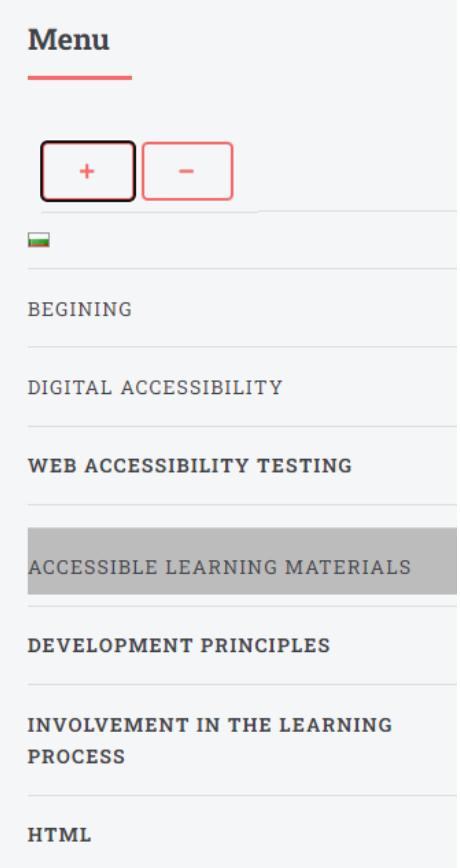

Figure 4. Custom zooming web control

```
document.getElementById('increaseText').addEventListener('click', () => {
    changeFontSize('increase');
})

document.getElementById('decreaseText').addEventListener('click', () => {
    changeFontSize('decrease');
})

function changeFontSize(operation){
    let elements = document.querySelectorAll('#main, #sidebar');
    elements.forEach((element) => {
        let currentTextSize = parseFloat(window.getComputedStyle(element, null).
            getPropertyValue('font-size'));
        switch (operation) {
            case 'increase':
                currentTextSize += currentTextSize * 0.1;
                break;
            case 'decrease':
                currentTextSize -= currentTextSize * 0.1;
                break;
        }
        element.style.fontSize = currentTextSize + 'px';
    })
}
```

Figure 5. JavaScript code of the zooming component

5. Conclusion

The paper presents a case study related to accessibility problems in educational process. A survey on the awareness of teachers in Bulgarian schools is performed and the results are introduced. Based on the studies and analysis, it was established that the problems of inaccessible educational resources are not well known to a large part of teachers in Bulgaria.

The need of accessible educational resources leads to systematic research on web accessibility recommendations presented in the third section of the paper. One of the main contributions of the paper is the created design and functionalities of the web portal for accessibility in STEM education. The information site contains accessible materials in the form of tutorials, publications and summary recommendations, increases the awareness of students (future teachers or web designers) and facilitates them in their work.

The results of the present study can be important for people with disabilities by improving the conditions in the educational environment, the quality of their training and their confidence in their personal capabilities in STEM subjects.

The future research could include implementation of the developed information portal and resources in the educational institutions and adapt it to their special needs. It is important to broaden the research groups to more educational institutions both inside and outside Bulgaria and in connection with this to localize the portal to more languages.

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