Article

An Ecosystem for the Provision of Digital Accessibility for People with Special Needs

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Abstract: Digital technologies occupy an important place in today’s developing world. They are also strongly related to new trends in educational technologies. In this context, the digital accessibility of this new environment for people with various special needs is of particular concern. A novel tool for assessment of the technological ecosystem, designed to provide digital accessibility to people with special needs, is described in the paper. The overall structure and the initial test of the system are discussed in the paper. The conceptual framework of the ecosystem and its ontological model are described. Special attention is paid to the accessibility of digital learning and e-learning for people with special needs from a robotic perspective.

Keywords: technological ecosystem; accessibility; people with special needs; robot assistants

1. Introduction

Digital technologies in the present day are interconnected globally, providing a dynamic environment to support the educational needs of any learner within novel technological ecosystems. A necessity of these technologies is them possessing emergent properties based on an understanding of disability as a discrepancy between a person’s goal and their available means (technological, social, cognitive or motivational) to achieve it [1].

World organizations such as the UN, the EU and state and international units continue to share good practices and recommendations on the use and implementation of strategies, policies and standards regarding people with special needs (PSN) and their participation in modern society (World report on vision [2]; Union of equality: Strategy on the rights of persons with disabilities 2021–2030 [3]; American Foundation For The Blind [4]).

According to the freely available data from Statista, as of 2020, Bulgaria is in 5th place out of 27 countries in the European ranking in terms of the share of people with vision loss according to the severity of the disability [5].

Since then, many steps have been taken to create conditions for the integration of PSN into and the participation of PSN in the modern economy and society, specifically people with visual impairments, such as:

- The European Accessibility Act (EAA), which was adopted in 2019 and entered into force in June 2022.
- Strategy for the Rights of Persons with Disabilities 2021–2030, which provides a framework for promoting the rights of persons with disabilities, accessibility, equality and the participation of people with disabilities, including blind individuals.
Standards such as EN 301 549 [6] and EN 17161 [7], providing guidelines and requirements for the accessibility of ICT products and services, which are crucial for ensuring that digital platforms and technologies are usable by people with disabilities, including those who are blind or visually impaired, etc.

The paper discusses the current state of the research and the development of the informational ecosystem as a tool for the provision of digital support to preschool and adult learners with special needs, as well as its future applications. The present study proposes a conceptual framework for teaching through cloud-based, cyber-physical systems. The research is being conducted as part of the project “Digital Accessibility for People with Special Needs: Methodology, Conceptual Models and Innovative EcoSystems” (AB) [8]. The project length is three years: 2021–2024. It considers two target groups: preschool children with cognitive disabilities (6–7 years old) and adults with visual impairments (40–50 years old) in Bulgaria. Most of the authors have been involved from the beginning of the project, and a researcher with a disability is included. It provides a conceptual model of the social-oriented ecosystem with instruments that contain semantic mechanisms for providing and validating accessibility. The given model provides several levels of accessibility barriers, as it keeps the person at the center [9]. The first layer is that of human knowledge and motivation. There, the main barrier is called intrinsic since it is one based on the learner’s personal traits and is used when the information is derived from the web or any other repository. Various tools and tactics are adopted in order to increase learner motivation, such as robots to enhance motivation while acting as mediators of knowledge [9,10]. The sensor barrier to knowledge is faced using an array of different modalities such as 3D-printed objects, Braille keyboards, etc., as well as with volunteers aiding in improving knowledge accessibility [11]. Social–economic barriers, experienced according to the affordability of courses, devices, etc., required by PSN, are marked as an external layer [12].

The main contributions of the present study are related to the application of various technologies to ensure better digital accessibility for people with special needs:

- Semantic technologies: A developed ontology of digital accessibility;
- Digital technologies: Conceptual model of an experimental socially oriented ecosystem and information site;
- Three-dimensional technologies/robotic technologies: Experiments, developed methodology and implementation;
- Cloud technologies: Online tutorials and ecosystem modules;
- Assistive technologies for people with disabilities.

More information about the project can be found on the project site [8].

This study examines current issues in digital accessibility for PSN, as the research was carried out within the framework of the AB project. In the Section 2 of the paper, a conceptual framework of a socially oriented AB ecosystem is presented. The ontological model of learning processes in the AB Ecosystem Tool is described in the Section 3. The Section 4 examines the accessibility of digital learning and e-learning for people with various special needs from a robotic perspective.

2. Conceptual Framework of the AB Ecosystem

Various models of semantic knowledge in the field of accessibility are being developed in the scientific community. Some of them emphasize the connectivity of accessible technologies and using them to overcome physical accessibility [13]. The interaction of accessible equipment and its adaptation to physical accessibility in specific cases are laid out in them [14]. As regards this point, Murillo-Morales and Miesenberger [15] use semantic technologies for affordable adaptation of digital images. In the same domain, the AB ecosystem adapts a variety of methods to provide greater semantic knowledge on accessibility.

Some of the studies propose methodologies that use semantic technologies to help accessible learning [16,17]. Most consider models of accessible knowledge presentation...
through lessons [18]. Some use semantic technologies to process learners’ responses and progress at a given stage in the education of people with disabilities [19,20].

The aim of this AB ecosystem is to assess the accessibility of digital resources after analysis [21]. The assessment considers accessibility for people with different needs, and in the case of an unsatisfactory assessment, various guidelines are indicated to deal with the barriers found.

The conceptual framework of the AB ecosystem consists of an ontology, on the one hand aiming to present key elements necessary for the creation of e-resources suitable for people with special visual needs and on the other hand aiming to provide guidance in the creation and maintenance of an e-platform containing such resources. The design of the AB site is ongoing. The objects in its structure are complemented by the team’s research on the current legislative framework and the ICT standards at the national and European levels when building digital resources for people with special educational needs.

The main objective of the AB project necessitates the creation and adaptation of optimal and applicable conceptual models for digital accessibility and learning in the field of accessibility. These models enhance and facilitate context-sensitive accessibility to digital resources and share knowledge in this domain in socially grounded ecosystems. Specialized training includes topics such as “what accessibility is and how to achieve it”, as well as teaching a variety of topics via cloud-based robotic systems to disadvantaged children. In Figure 1 is presented the conceptual structure of the AB system.

![Figure 1. The AB ecosystem’s conceptual structure.](image)

In the ecosystem, the main entities that will interact with the system are considered—software developers, teachers and learners. Contemporary trends in building electronic resources and/or platforms to help PSN are also reflected. The roles are also aligned with the hardware and software capabilities in creating and maintaining an e-platform and/or resources for visually disabled e-users.

From a user point of view, part of the conceptual structure of the system can give disabled people access to standards and regulations that are key to the social group under consideration, a space for discussion. In this space, it is appropriate to place information about legislative regulations at the national, European and international levels, including ways in which and means by which they can participate in the creation, discussion and voting of such citizens [22]. From an economic point of view, the subsection “Interact” enables the maintenance of up-to-date information for online users with visual disabilities, according to the following types of relationships:

- **C2C (Consumer-to-Consumer)**—sharing and searching for useful information and experience through discussion forums and/or social networks; informing the public; feedback.
- **G2C and C2G (Government ↔ Consumer)**—information to help the participation of interested parties in the processes of the integration of people with disabilities into the modern economy.
Digitization processes during the COVID-19 pandemic have shown the need for audio and audio–visual resources and assistive materials in teaching, in terms of general and specialized education, as well as lifelong learning.

The European Disability and Parking Card, valid in all member states, initiative is already underway, providing free access to some cultural and public institutions in the member states [23].

In the next section, the ontological structure for ensuring the educational processes in the AB system of Bulgarian citizens will be examined in more detail.

3. Conceptual Model of the Ontology Structure of Learning Processes in the AB Ecosystem Tool

An ontology is a formal explicit description of concepts in a domain of discourse called classes, with the properties of each concept describing various features and attributes of the concept and with restrictions on these properties [24].

The conceptual framework of the AB tool consists of an ontology reflecting the current need for a single online platform suitable for use by the blind in the country by using modern methods in the construction of an e-space and the relevant resources in it. The ontology describes the relations between the different domains of our accessibility knowledge base.

In Figure 2, the AB ontology is presented as a class hierarchy from the Protégé v.5.6.3 software environment. At the center of the ontology is the class Person. Individuals from this class represent the main types of ecosystem users. For the moment, these are learners (with possible disabilities, class Learner), developers of different software applications that are related to the ecosystem (class SoftwareDeveloper) and teachers involved in the educational process (class Teacher). Analogous to other similar electronic learning environments, the level of access of the individual here also depends on their position in the hierarchical structure. The following table describes the options for working with the system according to the role of the user (Table 1).

Here is a description in more detail of the main capabilities and interrelationships in the classes of the conceptual structure of the AB semantic hierarchy.

Using the class UserInterest, different types of interest topics and abilities of the users can be described in the ontology. An important part of the semantics is the class Disability. Its subclasses correspond to different types of disabilities considered in the research. Class Resource represents types of educational resources. There are classes in the ontology that represent documents classified as educational resources but that are also included in the ecosystem. These are all individuals in the subclasses of the class AccessibilityGuide. Resources can be referenced for individuals from the class Lesson, and all the lessons can be used for individuals from the class LearningCourse. The classes Robot and RobotType represent robots that can be used to assist the learning process.

Table 1. The possibilities of working with the system according to the user role.

<table>
<thead>
<tr>
<th>Activity</th>
<th>classSoftwareDeveloper</th>
<th>classTeacher</th>
<th>classLearner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create/update/delete role in classLearner</td>
<td>✓</td>
<td>✔</td>
<td>X</td>
</tr>
<tr>
<td>Create/update/delete role in classTeacher</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Create/update/delete a subcategory in the classDisability</td>
<td>✓</td>
<td>✔</td>
<td>X</td>
</tr>
<tr>
<td>Access to attendance data of e-users in classLearner</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Access to attendance data of e-users in classTeacher</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Create/update/delete association between classes “x”</td>
<td>✓</td>
<td>✔</td>
<td>X</td>
</tr>
<tr>
<td>Access to view resources in class “x”</td>
<td>✓</td>
<td>✔</td>
<td>X</td>
</tr>
<tr>
<td>Upload/update/delete a resource</td>
<td>✓</td>
<td>✔</td>
<td>X</td>
</tr>
</tbody>
</table>

In Figures 3 and 4 are presented some of the data and object properties in the ontology. The object property hasDisability and its subproperties assign list of disabilities to users. The property hasInterest assigns a list of interest to users. There are also object properties that represent relations between courses, lessons and resources. Guides, courses,
lessons and resources can be classified in terms of their appropriateness for certain disabilities and interests (the property isProperFor and its subproperties). The object property isAssistedBy assigns a Robot object to concrete Course or Lesson.

![Class hierarchy of AB ontology of accessibility on the Protégé platform.](image)

**Figure 2.** Class hierarchy of AB ontology of accessibility on the Protégé platform.

![Data property hierarchy.](image)

**Figure 3.** Data properties.

In Figure 5, examples of individuals in the classes Learner, Teacher, Resource and Lesson are presented.

Although there are specialized hardware and software options available on the market for the blind (laptops, mobile devices, specialized keyboards, etc.), access to them is not guaranteed for every visually disabled person. In this regard, the conceptual ontology of accessibility covers the quantitative and qualitative indicators of a suitable interface of the site and the available ICT resources, according to the requirements of the recently adopted

Figure 4. Object properties.

Figure 5. Individuals of classes (a) Learner; (b) Teacher; (c) Resource and (d) Lesson.
4. Accessibility of Digital and e-Learning for PSN from a Robotic Perspective

A new conceptual model for the effective delivery of Internet-gathered knowledge to children/learners with special educational needs using humanoid robots is described in [9]. The experimental situation is similar to one of Piaget’s tests to overcome the so-called “intellectual egocentrism” at the age of about 7–8 years. In this framework, children learn to “see” the world through the eyes of another person in the room. This projection is equally transferable to the NAO robot. The child infers a mental picture of the robot depending on the facts about the robot witnessing an action or not. Therefore, the implementation of robots improves the accessibility of scientific (digitally represented) knowledge by making it memorable and enjoyable.

A framework for an educational technology ecosystem in inclusive classrooms: The implemented technological ecosystem allows inclusive education to take place outside of any modern constraints associated with schools, such as reliance on average test performance to determine progress, a lack of attention to the individual student’s subjective state or comfort in a class, a lack of adequate attention to students possibly being vulnerable due to pre-existing conditions, including sensory deficits and learning difficulties, etc.

One notable feature of such a school is the emphasis on cooperation rather than competition in the classroom and the encouragement of the talent and imagination of all children. However, this inclusive classroom of future professions will require a higher level of robotic autonomy on the one hand and a greater degree of orchestration of software performance outside the classroom—i.e., in the cloud. A possible framework for such cloud orchestration is provided in Figure 6. The scheme illustrates the potential of the technology ecosystem to support each individual student during a lesson in a teacher-coordinated way. In addition, this support can be equally beneficial to both slow and fast learners and learners with sensory deficits.

![Figure 6. A computational framework for the classroom of the future based on the AB concept.](image)

In our study (2021–2024), we have tested the scenario on two different groups of people to see whether the effects on people with learning disabilities will be comparable to the demonstrations observed. Models and a system for accessibility analysis of digital and electronic learning systems have been developed, which extends the subject–object relationship by including robots in the interaction process. The training uses robotic technologies, in particular the robot NAO, as an active participant in conducting lessons for people with special educational needs (with an emphasis on people with cognitive and visual disabilities). In recent years, the project team has implemented accessibility training. For example, in 2021, training with NAO robots (active participants in teaching lessons) was conducted for children with cognitive disabilities, demonstrating a false belief task with two NAO robots [9].
In March 2024, educational experiments on accessible learning with NAO robots were held at the Spring Seminar of the Interdisciplinary Network “Information Society”, Veliko Tarnovo, with a target group of people with visual impairments, together with the Union of the Blind in Bulgaria, Veliko Tarnovo. A pilot study on the individual interaction of three participants (two men and one woman between 40 and 50 years old) with visual impairments with the humanoid robot NAO after approval by the ethics committee at the “Institute of Robotics—BAS” was conducted. A scenario, “Get to know the robot NAO”, was created, the purpose of which was to familiarize the participants with the robot. The idea is for the robot to talk about itself, what it is as technical equipment and what it can do. This allows visually impaired people to touch the robot, learn about its parts and feel the change in the robot’s posture. Tactile sensors on the robot NAO were used, where after pressure, the robot talked about the part of the body that was touched. A voice recognition mode, where the robot responded to a greeting and changed its posture in response to a voice command, was used. Communicating with the robot NAO was interesting for the participants. As a result of the research, we received positive feedback, which encouraged us to continue our research in this direction. During the tactile exploration of the robot and its buttons, NAO described each pressed item individually based on pre-recorded short operating instructions. The instructions programmed for NAO are intended to allow the robot’s body to learn on its own. Within the seminar, workshops were organized with two groups of participants—on the first day, teachers, including the blind, were present, and on the second, people from the Veliko Tarnovo branch of the Union of the Blind (Figures 7–9), were present.

![Figure 7. Educational experiment with robot and didactic materials.](image1)

![Figure 8. Educational experiments with robotic technologies in inclusive classrooms (first day of seminar).](image2)
A robotic ontology was formulated, containing explanations and tools for optimizing robot actions and roles in performing tasks in the innovative classroom based on the AB concept. A special feature of our approach is that the implemented AB framework aims to connect education and healthcare by applying conceptually similar concepts: the “cyberphysical teacher” and the “cyberphysical nurse”. The similarity is in the “essential” human characteristics implemented by the two robotic agents [27].

The AB system can be of great help in adapting the process of retraining and the rehabilitation of various functions to impaired individuals at any age. A crucial aspect of the application of robotic technologies in the social or health field is the student’s level of motivation to interact with the robot, which in itself is an important research topic. In this regard, an acceptable definition of a “cyber physical nurse” is offered in [27]: “If we imagine the ‘perfect’ robotic nurse, it would probably be a cyber physical agent best described as the 4Ps.”—“pleasant, patient, polite and imperious” (p. 36979). Similar characteristics are also “essential” to an acceptable cyber-physical trainer/rehabilitator. Future studies are planned to investigate the rate of recovery as a function of the degree of motivation in rehabilitation settings with robotic assistants in the healthcare sector.

5. Conclusions

The presented AB ecosystem is an open access multifunctional tool that assists in the process of checking an online space and/or its resources against its accessibility for visually disabled people in an electronic environment. The described set of objects in the ontology is based on the authors’ ongoing research into ways of maintaining e-spaces for visually disabled people and storing and distributing resources for the same public group. Considering the socio-cultural differences in individual countries and the legislation at the international and European levels, the possibility of connectivity and feedback between the interested parties in the processes of the integration of and work with the blind is foreseen. The proposed structure for building a learning environment in this space meets the current requirements for access to information and communication technologies for PSN. The described mechanisms for uploading, using and sharing resources envisage various types of materials—3D models, audio and video materials, training courses for working with programming languages and working with robotic systems. This ontology of accessibility allows us to classify the resources in it according to several indicators—according to the role of the user, their interests, degree and type of disability, the type of resource, etc. The presented ontology is expected to help e-users with visual disabilities and increase their digital skills, as well as current and future developers of technological solutions for the blind in the e-environment. The paper emphasizes the technical aspects, so future work will focus more on the educational aspect by developing learning materials and conducting additional experiments, extending the semantic knowledge to increase access for people with other disabilities.
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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Institute of Robotics, BAS, (protocol No 2/26.03.2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is contained within the article.

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