Chapter 4
The Potential of Artificial Intelligence for Assistive Technology in Education

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Abstract The right to education is a fundamental human right and an indispensable prerequisite for the development of human beings. To become well-rounded and independent from others, people with various disabilities should have an equal access to quality education. Assistive technologies support persons with different disabilities to keep and improve their functioning, which reinforces inclusive education. Artificial intelligence is their driving force, empowering a plethora of AI supported educational tools intended for people with special needs and elderly people, encompassing the tools for visual, hearing, communication, intellectual, cognitive and motor impairment. This paper also introduces the futuristic assistive technologies, in line with the prospective ethical challenges of AI supported educational tools.

Keywords Assistive technologies · Social inclusion · Visual impairment · Hearing impairment · Intellectual impairment · Cognitive impairment · Communication impairment · Motor impairment · Futuristic assistive technologies

4.1 Introduction

Artificial intelligence (AI) is becoming the most powerful and beneficial technology, positively impacting various daily activities [1]. It has significantly improved medical diagnostics, media and e-commerce, the service sector, transportation, education, and environment [2]. Natural language processing has enhanced and upgraded text and speech processing, morphological and syntactic analysis, and in recent years it contributed to lexical, relational and discourse semantics [3]. Although the quality of computational linguistics applications is still inferior to human achievements, the quality gap has considerably narrowed, making these applications very useful for

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practical use, particularly the machine translation and question answering. By establishing software robotics, which is usually synonymized with robotic process automation (RPA), AI supports the automation of digital and physical tasks, enables cognitive insights by detecting patterns within massive databases, and encourages cognitive engagement [4]. Accordingly, RPA is augmenting human capacities, amplifying effectiveness and improving quality of life.

By creating AI-based vision, cognitive, hearing and sign to text aids, AI has considerably powered accessible and assistive technologies [5], enabling people with various disabilities to reduce their psycho-physical barriers and inequality [6], and to encourage and support their social inclusion [7]. Education has significantly benefited from assistive technologies, reshaping the learning and teaching perspectives of millions and enabling the unhindered access to the wealth of knowledge [8]. It is part of the AI for social good (AI4SG) movement, which is a global trend aiming to improve the well-being of the world by implementing AI solutions [9]. It is undeniable that AI can have a great impact on education because it can easily detect students who might fall below grade level, determine the exact interventions necessary to support graduation on time and last, but not the least, AI can facilitate access to information to children with disabilities [10].

AI promotes personalization, ensuring inclusive education for all and better learning outcomes [11]. UNESCO working papers on education policies predict that the future with AI will be beneficial for the sustainable development of education, particularly if the six challenges, including the comprehensive public policy; teachers' preparation; ethical considerations as well as the increased research are seriously taken into account [11]. Particularly important is to ensure inclusive education and equity, making AI for education a core value [12]. According to the International Telecommunication Union (ITU), a specialized agency responsible for information and communication technologies (ICT) by the United Nations, ICT accessibility should become the main priority for persons with disabilities [12]. Since 2014, when the above-mentioned assertion was published, ITU has concluded that namely the AI is the science that "has the potential to support and enhance the accessibility of ICTs" [13]. Illustrating that the current intersection between accessible ICT, assistive technology and AI is small, ITU concludes that "AI use in the field of ICT accessibility is still in its infancy" [13].

Pandemic conditions and the necessity to replace in-class learning and teaching with digital accessibility made the accessible and assistive technologies more necessary than ever [14]. Many initiatives were immediately put into action, such as Digital Education Action Plan [15], iTutor in USA (https://itutor.com/), which is one of the many successful intelligent tutoring systems [16], and Get Skilled Access in Australia [17]. So far, there is no official report evaluating their accomplishments. Thus, it is crucial to know how to reach the available assistive tools and how to achieve a greater accessibility for everyone who needs it.

This paper presents a plethora of AI supported educational tools proposed for people with special needs. The main motivation to start such a comprehensive review was the author's long-term experience with assistive technologies [18], which among other educational systems includes the avatar visualization of Macedonian sign

language intended for people with communication intelligibility [19]. The appreciation of the exceptional effects of AI-powered inclusive educational tools was recently intensified by the fact that they transformed the life of the girl with cerebral palsy [18]. Little V, now in her mid-twenties, managed to overcome most of her educational barriers caused by cerebral palsy and she is a very successful student of graphical design who competently uses an adapted keyboard and mouse to make fascinating drawings.

The systematic review presented in this paper intends to make a summary of the current research confirming that AI can have a great potential for assistive technology of education. It predominantly covers papers and reports published after 2015.

All the AI-supported tools presented in the paper were first selected implementing qualitative and quantitative ranking of papers selected from WoS master journal list and core collection. There were several qualitative criteria defined by the author: type and diversity of embedded AI agents, operating systems portability, multilingualism, and price. Presence of several AI-enhanced accessibility options, possibility to activate them from different devices, availability in the native language of the students, and the price, increase the availability of technological tools for users with disabilities. The second part of search methodology was quantitative ranking. It organizes the clusters of similar tools according to their number of users and the approval rate given by the users, whenever this information was provided. For each disability, five tools were taken into consideration for further analysis. Due to their massive usage and their impact on inclusive education, the amount of tools for visual impairment was doubled. The review starts with the text-to-speech, magnifying and tactile software for learners with visual impairment; speech-to-text and word prediction systems for learners with speech or communication disabilities; text-to-sign language converters, assistive listening devices and mobile applications for learners with hearing impairments; word recognition, math, spelling and social skills applications for people with intellectual disabilities; and cognitive orthotics and assistive technology for augmenting learning, cognition and development. It further presents the AI assisted mobility impairment. The last part of the paper embraces the futuristic assistive technologies and neural implants, which synchronize AI with human brain. The paper concludes with the contribution of AI for education, tackling the prospective ethical challenges of AI supported educational tools.

4.2 Learners with Visual Impairment

According to the World Health Organization, blindness and visual impairment affect at least 2.2 billion, or approximately 28% of world population [20], out of which almost 50 million are blind [21]. Reduced or absent eyesight disturbs all aspects of life, causing disabled communication, social isolation, depression, cognitive decline and even an increased risk of premature death of elderly people, who lose their independence.

In the last several decades, many assistive technologies for the visually impaired and blind people have been developed, enabling people to "overcome various physical, social, infrastructural and accessibility barriers" and facilitating them to "live active, productive and independent lives" [22]. Computer accessibility settings, modified keyboards, electronic books, talking calculators, image descriptors, visual localization systems, screen magnifiers, screen readers, voice assistants, tactile dots and text to Braille translators are nowadays used to support education of visually impaired or blind students. The following paragraphs introduce the most popular educational tools and their connection with the AI.

The most frequently used desktop operating systems: Windows, macOS and Linux, and mobile operating systems: Android and iOS have built-in accessibility features intended for blind and low-vision users, such as screen readers of text-to-speech (TTS) synthesizers, high-contrast themes and enlarged cursors. All Web browsers offer accessibility features for zooming the displayed screen content.

Modified keyboards for visually impaired persons range from keyboards with larger letters or large print stickers to tactile Braille keyboards [23]. Electronic books are special text collections of books, magazines, and newspapers formatted to be accessible to persons with visual impairments and blindness [24]. None of these technologies is AI supported, but their educational impact is significant, particularly because they are available to all the students for free. For example, Talking Books (rnib.org.uk/talking-books-service) gives free access to 32,000 books for adults and children, while Project Guttenberg (gutenberg.org/) has a collection of 60,000 books. Many countries have similar initiatives, creating collections of audio books, for example: in Serbian (knjigaprica.com/), Russian (akniga.org/) and Macedonian language (samoglas.mk/). To create these collections, many voice actors were engaged to read the books. Good quality TTS readers can efficiently replace them. TTS engines already power talking calculators, which have a built-in speech reader responsible to read the pressed keys and the result of the performed arithmetic operation [25]. Many of them are supplemented with voice-controlled interfaces, enabling a calculation of spoken operations and equations [26].

Image descriptors are written captions, which provide the essential information about photos, graphics, gifs, and video. Automatic image captioning combines computer vision and deep learning techniques to create the captions and converts them into a speech by implementing natural language processing (NLP) procedures [27].

Visual localization systems replace the conventional assistive tools, enabling easy navigation and supporting the awareness "of ambient environments and prevents them from coming across potential hazards" [28]. To perform this task, these systems, for example GoogLeNet, employ the deep convolutional neural networks [29].

Screen magnifiers enlarge the screen display, supporting the low-vision users. Most of the modern desktop magnifiers, such as: DaVinci Pro HD OCR, Onyx OCR 24, Merlin Elite Pro–Full HD Desktop and TOPAZ OCR Desktop Video Magnifier are enhanced with high definition cameras, optical character readers (OCR) and TTS readers [30].

Text magnifier and reader ZoomText (zoomtext.com/) is powered with the world's leading screen reader, JAWS for Windows, making the Fusion (freedomscientific.com/products/software/fusion/), a "screen magnification and visual enhancements for screen viewing ease". From the beginning of March until June 30 2020, free licenses were offered to facilitate the blind students study at home.

Voice assistants, such as: Amazon Alexa, Google Assistant, Apple Siri, Microsoft Cortana and Samsung Bixbi incorporate voice recognition, speech synthesis, and many NLP techniques, making them one of the most successful AI-complete applications. They can also have a great potential in education [31]. Unfortunately, due to the various privacy concerns and vulnerability of the channels by which personal data can be accessed [32], they might be counterproductive for the students with disabilities, particularly those who are not IT savvy.

For the deaf-blind students, who are estimated to be around 10,000 only in the United States [33], tactile assistive technologies seem to be the best accessibility solutions for everyday activities and education. They range from tactile dots, via haptic interfaces to text-to-Braille translators.

Tactile dots or bumps enable easier orientation at home or in the office achieved by marking computer keyboards, phone keypads, remote controls and home appliances with peel-and-stick bumpers (braillebookstore.com/Bump-Dots.1).

Haptic interfaces are tactile devices, which enable getting a sense of touch "by applying forces, vibrations, or motions to the user" [34]. Haptics has already been used to support the teaching of physics, chemistry and biology, providing alternative educational settings where students can manipulate and experience physical properties of objects, or molecular and microscopic structures thus allowing a richer understanding of concepts [35]. So far, there have been very few attempts to use haptic perception as an educational assistive technology [36], but haptics has the ability of full inclusion of blind students making it very promising for the future education of all students.

For the students who are familiar with the Braille alphabet, a variety of electronic devices, which embrace Braille note takers, writers and displays have been created [30]. Some of them enable bidirectional translation, from text to Braille and from Braille to text, enhancing writing and reading skills of blind students, without the need of a Braille teacher [37]. These technologies perform the OCR implementing various machine learning (ML) practices [38].

Table 4.1 on the following page presents 10 very popular AI supported educational tools for vision impaired students. They all contain a text-to-speech synthesizer, usually leveraging neural network techniques to deliver a human-like voice. NVDA and JAWS, which are the most frequently used screen readers have additional languages apart from the default English. NVDA is powered with Acapela TTS voices, supporting 28 languages and implementing 90 quality voices (acapela-group.com/solutions/acapela-tts-voice-for-nvda/). Screen magnifiers are not AI driven tools, but document readers, which are a complementary part of ZoomText Fusion and Select-to-Speak implement OCR of written or printed documents, mainly powered by neural networks (NN) [39]. The newest versions of JAWS, ZoomText, and Fusion interact with the users via their Voice Assistant, which supports

Table 4.1 AI supported educational tools for vision impaired students

Assistive tool	URL to access the tool	Features	AI agents	Availability	Price
JAWS (Job access with speech)	support.freedomscientific.com/	Screen reader Image description Voice Assistant	TTS NLP	Windows English Dutch German Spanish French	Home US only: $90 per year
NonVisual desktop access (NVDA)	nvaccess.org	Screen reader Braille display	TTS	Windows web based 50 languages	Free
ZoomText	zoomtext.com	Screen magnifier Screen reader	TTS NLP	Windows english	Home US only: $80 per year
ZoomText fusion	zoomtext.com	Screen reader Document reader Text magnifier Braille support	OCR TTS NN NLP		Home US only: $160 per year
DaVinci Pro HD OCR	nelowvision.com/product/davinci-pro	Video magnifier Speech reader	OCR TTS	Windows english	$3995
Onyx OCR 24	store.freedomscientific. com/products/onyx-ocr	Video magnifier	OCR TTS	Windows english	$3795

(continued)

Table 4.1 (continued)

Assistive tool	URL to access the tool	Features	AI agents	Availability	Price
VoiceOver	apple.com/accessibility /vision/	Screen reader Auditory descriptor	TTS NLP	macOS iOS English Spanish	Free
VoiceOver+Braille	apple.com/accessibility/ vision/	Screen reader Auditory descriptor Braille input	TTS	macOS iOS iPadOS English Spanish	Free
Select-to-speak	support.google.com/accessibility/android/answer/7349565?hl = en	Screen reader Document reader	TTS	Android	Free
Web anywhere	webinsight.cs. washington.edu/wa/	Screen reader	TTS	All operating systems	Free

English, German, Dutch, Spanish and French (blog.freedomscientific.com/whats-new-in-jaws-zoomtext-and-fusion-2021/).

Half of the presented assistive technologies are free, making them very popular. For example, NVDA is currently used by more than 70,000 vision impaired students worldwide. It announces controls and text while interacting with gestures on touch screens. Most of the commercial products are offered for an affordable price for home or student use. Unfortunately, corporate versions are too expensive, disabling their massive use. Still, the major challenge of all the solutions is the limited amount of languages and the availability for one operating system.

4.3 Learners with Hearing Impairments

According to the World Health Organization, more than 450 million people have hearing loss, 34 million of them are children [40]. Apart from congenital and acquired causes, including genetic problems, infectious diseases, ear infections, excessive noise, and ageing, more than 1 billion young people "are at risk of hearing loss due to exposure to noise in recreational settings" [40]. Hearing loss and deafness have: a functional impact affecting the ability to communicate and become academically successful; social and emotional impact, due to exclusion from communication; and economic impact, because the unemployment rates for people with hearing loss are high.

According to the US National Institute of Deafness and other Communication Disorders [41], to help people with hearing disabilities, three types of assistive technologies can be implemented: alerting devices, assistive listening devices, and augmentative and alternative communication devices.

Alerting devices emit a loud sound or blinking light to inform the person with hearing loss about some event. They typically include clocks, wake up alarms, visual alert monitors, remote receivers, and vibrating pagers [42]. AI contribution in these devices, if it exists in any way, is negligible and therefore, they will not be further explored.

Amplification of sounds is made with the assistive listening devices (ALD), mainly hearing aids or cochlear implants. They include: hearing or induction loops systems, which amplify the sound within a public area and is received by the hearing aids and cochlear implants; FM or infrared systems, which transmit amplified sounds in classrooms; and personal amplifiers, which increase sound levels and reduce background noise [43]. ML technologies are implemented to optimize speech and signal processing, and to measure or support the evoked potential, prediction of postoperative performance and surgical anatomy [44].

Augmentative and alternative communication (AAC) devices incorporate various communication methods, which supplement or replace speech or writing [45]. They range from picture boards and touch screens presenting symbols or items the person frequently uses; devices projected to communicate words; and speech generating

devices [46]. In recent years, brain-computer interfaces for AAC communication have been invented [47]. They will be explained in more detail in Sect. 1.8.

AAC devices can be unaided and aided [48]. Unaided AAC are software solutions, which use facial expression, vocalizations, gestures, and sign language and systems to replace the spoken language [49]. The generation of visual alternatives, typically implementing 3D avatar technology, relies on word tokenization, which embeds several ML and NLP tools, including semantics [50]. For sign language recognition, supervised support vector machine learning models are used [51].

Aided AAC are devices used to transmit or receive messages, incorporating processes for augmenting, complementing or replacing speech [52]. They are divided into no-tech, low-tech and high-tech [52]. The first two categories have been used for decades, and they embrace facial expressions, voluntary motor movements and communication boards or books. High-tech AAC are AI supported, typically implementing machine learning and deep learning. Special education teachers emphatically endorse high-tech AAC tools, suggesting that AAC can "improve the experiences of teacher and student users" [53].

Table 4.2, presented on the following page, offer an overview of five of the most frequently used AAC applications and devices, which can be used at school enabling a better communication of hearing impaired students.

TapSOS (tapsos.com/) is a non-verbal application associated with British Telecom since 1993, enabling "UK citizens who are deaf, hard of hearing, have speech problems, or are in difficult situations" to access the emergency services by simply tapping over the icon of a required service, indicating the location and providing

Table 4.2 AI supported educational tools for hearing impaired students

Assistive tool	URL to access the tool	Features	AI agents	Price
Roger voice	rogervoice.com/en/	Calling and receiving phone calls	STT TTS	$5.99 per month
Ava	ava.me/	Lip-reading Live transcription	Visual speech recognition	$14.95 per month
Signly	signly.co/	British sign language translation	Pattern matching TTS	Free
VoxSci	voxsci.com/	British sign language translation	STT	£5 per month
Logan ProxTalkerMid-Tech AAC device	logantech.com/products/proxtalker	Sound tagger Picture system RFID technology	Pattern matching NLP	$3149

more detailed information about the accident by tapping the additional icons. It is neither AI supported, nor intended for schools, but is one of the most valuable lifesaving applications, and deserves to be mentioned.

Rogervoice is an application that produces live transcriptions during phone calls. The transcriptions from text to speech (TTS) are available for more than 100 different languages. The application was currently used to facilitate more than 1,500,000 phone calls worldwide. Very similar application intended for mobile phones is Live Transcribe (android.com/accessibility/live-transcribe/). It includes 70 languages and dialects, which are transcribed using Google's speech recognition technology as they are spoken.

Ava (acronym for Audio-Visual Accessibility) is a mobile application capable of lip movement recognition, which presents live transcriptions. To perform the lip reading, Ava implements several AI techniques belonging to visual speech recognition, including speech recognition, speaker recognition and mining of multimedia content. Ava has a special program for schools, including online classes. According to Ava team, more than 150,000 people and many institutions use it.

Signly is a browser extension for Google Chrome and Microsoft Edge, which displays a sign language translation of Lloyds Bank and Network Rail website. It currently has no educational purposes, but the same approach might be incorporated into many educational sites to display sign language descriptions of the lectures.

Available on both, AppStore and Google Play, VoxSci transcribes voice messages into text messages, which are delivered to hard of hearing and deaf as SMS to mobile phones, or as e-mail to e-mail addresses. For a monthly price of 5 British pounds, they provide translation of 30 voicemail texts, making it slightly inconvenient for educational purposes.

The Logan ProxTalker has 80 prerecorded sound tags, which are placed over 5 location buttons. After being pushed, they generate a voice output. This AAC device has additional large tags for the students with visual impairment, and it is wheelchair mountable.

This section presented a range of tools and devices for hearing impaired students. They are accessible to many young students, mainly by offering a written transcription of spoken language. Surprisingly, very few applications are intended to use the 3D avatar sign language representation.

Interpretation of sign language gestures of US English has been patented in 2011 [54]. By that time, very few applications enabling sign language interpretation have been created [55]. They will significantly improve communication of deaf students with their teachers who are not skilled in sign languages. These tools are predominantly machine learning [56] and NLP based [57], showing the potential of artificial intelligence to support education of hearing impaired students. So far, there is a shortage of competent sign language interpreters, and in spite of the exceptional intellectual skills of some deaf students, many of them are not able to continue their education mainly due to communication barriers. An additional problem is the fact that only 17% of deaf or hard of hearing people use any hearing aid [40]. By creating new and affordable AI based technologies, the situation will undeniably improve.

4.4 Learners with Speech or Communication Disabilities

Speech disorders, sometimes called speech impediments embrace "difficulties with forming specific words or sounds, as well as difficulties with making words of sentences flow smoothly, like stuttering or stammering" [58]. They can be combined with language disorders, like aphasia, which is a difficulty of speaking parts of language and auditory processing disorder, i.e. a difficulty to understand the meaning of the sounds [58]. Additionally, many students have communication problems of different origins [59]. Speech-to-text and word prediction systems are the first solutions intended for learners with speech or communication disabilities. Recent survey of text-to-speech software suggests the commercial text-to-speech applications: Dragon Anywhere, Dragon Professional, Otter, Verbit, Speechmatics, Braina Pro, Amazon Transcribe, Microsoft Azure Speech to Text, and Watson Speech to Text, and the free solutions: Google Gboard, Just Press Record, Speechnotes, Transcribe and Windows 10 Speech recognition [60]. Their capabilities are fascinating, in some cases reaching an accuracy of 99.9% when the audio is clear. According to provided information, Speechmatics and IBM Watson Speech to Text use machine learning to correct those errors that were flagged up by their users, to prevent their repetition.

Word prediction systems detect the sequence of typed characters and suggest the prospective words in a prediction list. They are built into word processors [61]. Very popular are two mobile word prediction applications: Co:Writer Universal (cowriter.com/) and Dyslexia Keyboard (ghotit.com/).

For many researchers, the best solution to help children overcome their communication problems are the augmentative and alternative communication (AAC) tools [59]. The Logan ProxTalker has already been introduced in Sect. 1.3. AssistiveWare (assistiveware.com) suggest three mutually compatible AAC products: Proloquo4Text. Proloquo2Go and simPODD. They support non-verbal expression of children with various communication problems and speak the created words, phrases and sentences using human-like voices.

Proloquo4Text is a TTS supporting easy expression, implementing word and sentence prediction. It is multilingual and includes the following 9 languages: English, Danish, Dutch, French, German, Italian, Norwegian, Spanish, and Swedish. For a price of €129.99, it can be used on iPhone, iPod and Apple Watch users.

Proloquo2Go is a symbol-based application, which has an incorporated word vocabulary of more than 10,000 words developing full grammatical sentences. It presents a set of the so called core words, the words that are the most frequently used to make up 80% of what people say. Proloquo2Go is easy customizable, offering the creation of own buttons from existing 25,000 symbols, which can be extended with own photos. Similarly to Proloquo4Text, it is available for the same Apple's devices for English, Spanish, French, and Dutch for €279.99. Together with Proloquo4Text and Pictello and Keedogo (Plus), an application for reading, writing and typing using a simplified keyboard layout, they make the AAC Essentials Bundle for a unique price of €329.99.

PODD is an acronym for Pragmatic Organisation Dynamic Display, a "huge book of laminated pages and complex symbols". PODD is suitable for users who cannot speak. They can combine the symbols to explain the message they are not able to pronounce. simPODD is usually combined with Prologui2Go, extending the basic symbols with the large list of own symbols. For an annual price of €149.99, it is available from App Store.

Speech and communication disabilities affect comprehension, and production of oral and written language. They are frequent, affecting from 7.7% of young children in US [62] to 10% in UK [63]. Speech and language therapies are the most common methods to prevent, assess and treat these communication problems. Language therapists, known as logopedists are the specialists who employ these methods to assist the disabled children in their communication. It is projected that their employment will grow 25% in the following 10 years [64]. Speech-to-text and word prediction systems are a beneficial alternative of logopedists for those students whose deficiency is connected with hearing disorders, voice and speech problems. For the students with some additional problems, for example, autism, developmental and learning disabilities, AAC can facilitate communication. Unfortunately, all the available AAC systems on the market at the moment are rather expensive and created for a limited amount of languages, making them helpful for the privileged students, whose schools and parents can afford using them as a complementary communication tool.

4.5 Learners with Intellectual Disabilities

Intellectual disability is a neurodevelopmental disorder, demonstrated by limitations in cognitive functioning and adaptive behavior [65]. It affects communication, social and self-care skills. According to some sources, approximately 200 million people have an intellectual disability, which is significantly more frequent in the low-income countries [66]. Unfortunately, intellectual disability is not curable, for that reason, the treatment should be directed towards normalization of behavior and gaining emotional well-being of the people with limited intellectual abilities [67].

To "protect and ensure the full and equal enjoyment of all human rights and fundamental freedoms by all persons with disabilities, and to promote respect for their inherent dignity", UNESCO has adopted the Convention on the Rights of Persons with Disabilities [68]. Among the 50 articles of the convention, the two crucial for this paper are accessibility and education. In the recent years, many assistive technologies have been created but very few are intended for the intellectually disabled students [69]. Several computer and electronic devices for children with learning disabilities, such as: alternative keyboards, audio books, electronic math sheets, graphic organizers, speech readers, spell checkers and word-prediction applications can be beneficial for children with mild intellectual disability. However, much more has to be done to reduce their eternal struggling with the attention, learning and completing of educational tasks.

Table 4.3 AI supported educational tools for intellectually disabled students

Assistive tool	URL to access the tool	Features	AI agents	Price
Co:Writer universal	cowriter.com	Word prediction Topic dictionaries	STT TTS	$4.99 per month
Ginger	gingersoftware.com/solutions/ld_professionals	Spelling check Grammar check	NLP	Free
Inspiration 10	inspiration-at.com/inspiration-10	Mind-mapping Concept mapping	TTS	£58 or €67 without VAT
Lingraphica AAC	aphasia.com/	Communication AAC tool	TTS	Covered by Medicare Medicaid
Beamz interactive music system	thebeamz.com/	Interactive music making	Eye tracking	From $370 to $530

Major goal of assistive technologies for intellectually impaired is to improve their information access. To achieve this goal, AI based solutions have been developed, each enhancing or supporting a different aspect of student's academic and home life. They are presented in Table 4.3.

Co:Writed Universal was already mentioned in Sect. 1.4 as one of the best systems for word prediction. It also enables spelling correction, reading of the text while it is typed, opportunity to dictate the text, as well as dictionaries which suggest the corresponding vocabulary related to the topic a student is working on.

Ginger supports students with learning disabilities to easily write error-free texts offering clues how to carry on with the sentence, based on the context of the already written words. Within its premium edition, TTS feature reads the words together with a brief explanation of its meaning and a list of alternatives. Audio assistance is available in UK and US English.

Inspiration 10 is one of the most popular mind-mapping applications. Improved with UK and US spelling, this application enables students to create mind and concept maps and to organize graphic organizers, outlines and presentations. Moreover, it enables adding notes to symbols, text-to-speech and spell checking. Mind-mapping software will be explained in more details in Sect. 1.6.

Lingragrafica is an AAC application intended for people who survived a stroke or brain injury. It is a speech generating device, based on a system of icons that feature pictures, text and verbal output. They can also be a valuable tool for children with developmental or intellectual disabilities, which have trouble to communicate.

Beamz Interactive Music System is a versatile device accessible to students of all learning and physical abilities. It is intended for home use, for therapy and rehabilitation and for schools. Beamz is powered by Tobii EyeGaze (tobiidynavox.com/), an eye tracking technology that allows interaction, navigation and control of the devices by eye movement. Beamz is not an educational tool, but it has a very nice emotional impact for the intellectually disabled.

For centuries, people with intellectual disabilities were totally excluded from any education. Inclusive education has contributed to their active involvement and engagement enhancing their well-being. New assistive technologies are steadily improving their community living, improving their abilities to communicate and express the needs in a completely new way. Artificial intelligence is the core of most assistive technologies intended for these vulnerable and generous people who deserve a better and more dignified life.

4.6 Learners with Cognitive Disabilities

In the past, cognitive disabilities were equated with intellectual disabilities [70, 71]. Recent studies recommend to consider aphasia, autism spectrum, attention deficit, dyslexia, dyscalculia, intellectual and memory loss as a separate disability type, particularly because they do not necessarily affect general intellectual skills [72].

Cognitive disorders encompass problems with attention, processing speed, short-time and long-term memory, logic and reasoning, language processing, as well as math processing [73]. According to this detailed review "attention, processing speed, and short-term memory are part of automatic processing", while "long-term memory, logic and reasoning, language processing and math processing are part of higher thinking". As a result, cognition impaired have a diminished independence, which affects their daily activities, entertainment and social activities, and engaging in work.

Assistive devices intended for students with cognitive impairments are known as cognitive assistants [74]. These are interactive AI systems intended to improve the daily activities and education of the users "by augmenting their cognitive abilities or complementing a cognitive impairment" [74], thus they are a part of the cognitive orthotics [75]. Cognitive orthotics assistants are ubiquitous and pervasive platforms and services, aimed to support learning, memory, keeping records, making documents and organizing the thoughts [76].

All the above mentioned cognitive features are part of the mind-mapping or concept-mapping applications, software tools that enable the creation of visual diagrams, which can further be exported into documents, spreadsheets or presentations [77]. Many universities worldwide, particularly in the UK, have uploaded mind-mapping software together with magnification and screen-reading applications on all computers on campus.

Mind-mapping, concept-mapping and argument-mapping software packages are valuable mapping tools, which "enable the visual display of information, concepts and relations between ideas" [77]. They stimulate creative thinking of students and

Table 4.4 Mind-mapping applications for cognitive impaired students

Mid-mapping tool	URL to access the tool	Features	AI agents	Price
XMind 2020 Mobile	xmind.net	Brainstorming Planning Problem solving	Spell checking ML	$39.99 per 6 month
XMind 8 Pro	xmind.net	Brainstorming Planning Problem solving	Spell checking ML	$59 for teachers / students
MindView AT	matchware.com/assistive-technology-software	Visual planning Screen reader	STT TTS	$15–$20 per month
Mindomo	mindomo.com	Project planning Learning skills Thinking skills	Spell checking screen reading STT	€3 for students €5 for teachers per month
Popplet	popplet.com	Drag and drop visualization Collaborative brainstorming	Not specified	$19.99 per year for students

increase the achievements in learning science [78]. The in-depth survey of their impact on students with mild to moderate cognitive impairment has confirmed that the majority of reviewed students had a subjective impression that their functional performance has improved after implementing mind-mapping software [79]. Table 4.4 presents the most frequently mind-mapping applications used in education.

XMind is a cross platform tool used by tens of million users. Apart from enabling graphical representation of some problem, it is also useful for collecting notes, which can be organized in a graphical way and exported in a structured document. XMind has already in-built conceptual maps, enhancing visual perception of some well-known problems. XMind versions can be adjusted to support many languages, including Chinese, English, German, Indian, Japanese, Portugese, Russian, Slovenian and Spanish. They can be added into an own dictionary to facilitate the spell checking. XMind has several versions, including the mobile XMind 2020, and the professional XMind 8 Pro. The only AI feature they support is spell checking. XMind is dual licensed, under the EPL, with the prices indicated in Table 4.4 and under the LGPL.

MindView AT is an assistive technology for academic purposes. In parallel with the intuitive visualization, it includes text-to-speech, Dragon speech-to-text add-on, word prediction and high-contrast mode. Moreover, it enables easy integration

with JAWS and ZoomText, making it available for multiple disabilities. Similarly to XMind, it has around 100 education examples in several disciplines, like history, geography, languages and physics, which are very intuitive and facilitate remembering by visual stimuli. At the moment, it is available for Windows and MacOS in English, French and German. Monthly price depends on the period of subscription, which is annual, for two or for three years.

Mindomo is a browser based mind mapping assistive technology intended for students who suffer from Dyslexia, ASD, ADHD or who are easily distracted. Considering the fact that "90% of information transmitted to the brain is visual" [80], Mindomo presents information and details with colorful and interesting structured graphs. Visual presentation is extended with audio explanation, contributing to a better comprehension of presented information. Basic functionalities are available in a free limited option, which is appropriate for training the students to use the application prior to start using it at school.Popplet is recommended for younger students, including the K-12. It is used in more than 100 different languages, mainly due to their predominantly visual and very intuitive approach. Popplet supports individual and group subscriptions, which is convenient for younger students, for whom teachers set up student accounts and then oversee the use. No AI features are reported about this application, making it inconvenient for students with more severe vision impairment.

A more powerful instrument for students and teachers with cognitive disabilities are the assistive technologies for augmenting learning, cognition and development. A very exhaustive review of assistive technology for cognition (ATC) was made by Gillespe, Best and O'Neill [81], proposing a division of ATC devices into "those that affected self-awareness and those that involved the prioritization of action". They include word prediction software, voice recorders, speech recognition, cueing/memory aids and educational software. Cueing/memory aids are the most frequently used ATC gadgets, which help people to recall various information, ranging from tasks and appointments to steps in how to accomplish activities. The most valuable ATC for educational purposes are Read and Write Gold (texthelp.com/en-gb/products/read-write/) and Kurzweil 3000 (kurzweiledu.com/k3000-firefly/overview.html). Read and Write Gold is used by more than 25 million users who improve their reading and writing, including students who have dyslexia. It has an advanced spellchecker and word prediction module and reads the online text to "give tired eyes a break". Moreover, it increases concentration by masking the screen. Kurzweil 3000 is a universal assistive technology with several features for vision impaired, like text-to-speech, OCR and text magnification. It is adjusted for students with dyslexia, including a talking calculator.

Cognitive disabilities affect communication and learning, inhibiting life and school activities. Many assistive technologies can contribute to their reduction, particularly those which are associated with vision or hearing impairment and lack of concentration.

4.7 Learners with Mobility Disabilities

Mobility disability or impairment is any disability that affects movement. It includes upper or lower limb loss or disability, lack of manual dexterity and disability in coordination with other parts of the body. The World Health Organization estimates that 75 million people, or around 1% of world population need a wheelchair [82]. Wheelchair accessibility is a privilege for many students, particularly in the developing countries. Knowing that education is a fundamental human right, many students are discriminated on the basis of motion disability. Apart from wheelchairs, students can access schools using the mobility aids like walkers, scooters, crutches, canes, prosthetic and orthotic devices [83].

Many adaptive tools, including modified keyboards, specialized handles and grips, adaptive sticks, mouth sticks, automatic page turners, and sip-and-puff systems can support them in performing various tasks at school [84].

There are very few specialized assistive technologies for students with mobility impairment. One fantastic application, which is available for Android devices is Mouth4All Switch (mouse4all.com/en). It can assist students with "cerebral palsy, spinal cord injury, ALS, multiple sclerosis, Parkinson, neuromuscular disease" to manipulate the touchscreen without a need to touch it. Instead, an AAC approach is enabled, based on switch access scanning, which activates the selected option either by highlighting the items on the screen, or by announcing the items via voice output. Currently, it is available in Spanish and in Italian for $7.99 to $99 per item.

The most popular switch access scanning assistive technology is the Assistive Context-Aware Toolkit (01.org/acat/). It was used by Stephen Hawking since mid-1980s. It is free, open source application currently available in English, French, Spanish and Portuguese. Powered by Microsoft's Speech Synthesizer API and the default TTS voice on the target machine, it can be easily extended to other languages. ACAT has a vision switch using "the webcam to track the user's face and to detect facial gestures". To accelerate the creation of the words, it has a word prediction option.

The mobility aids and adaptive tools are not covered in this paper. Some of them are not AI supported, others are not intended for education. The development of many assistive and adaptive tools for motion impaired people is still in its infancy. Some of them belong to futuristic assistive technologies, which will be clarified in the next section.

4.8 Futuristic Assistive Technologies and Neural Implants

Small Danish startup Envision (letsenvision.com/) modified Google glasses turning them into AI-powered smart glasses, which extract information about the world surrounding the blind person and interpret them using a natural language. This is a nice opportunity to experience the visual world hands-free. Envision glasses are

powered with a text recognition module, enabling students to listen the content of their study materials. These glasses are non-invasive, but still unexplored and a rather expensive solution, with a pre-order reduced price of $1699.

Students and teachers with vision impairment caused by degenerative retinal diseases or age-related macular degeneration can undergo a surgical treatment to get a cortical and retinal implant, i.e. a bionic eye [16]. This is a very innovative assistive technology at its initial stage and very few companies and research groups have advanced enough to start producing them massively [16]. Moreover, they are extremely expensive, for example, Argus II and Orion, the only FDA approved bionic eye costs $150,000. Orion is one of the first implants inserted to human brain.

Many hearing impaired students use cochlear implants [85]. These small electronic devices stimulate the cochlear nerve, permitting people to gain better hearing and speech perception. Those students who received their cochlear implants during early childhood managed to gain an ability for better pronunciation, which resulted in a more expressive and receptive vocabulary [85].

Auditory brainstem implants (ABI) have been researched for almost 50 years and the results are very promising for all ages, including children who managed to achieve an environmental sound awareness and word detection few months after ABI was activated [86]. A more futuristic assistive technology than the bionic eyes is the optogenetic sensory restoration of hearing [87]. Optogenetics uses the light to control genetically modified cells and selectively stimulates or inhibits neural pathways. Future optical cochlear implants, powered by optogenetics can improve speech recognition [81]. Additionally, the same approach can be used to restore vision [88].

The futuristic assistive technologies "used to treat disease, rehabilitate the body after injury, improve memory, communicate with prosthetic limbs, and more" are the neural implants [89]. Neural implants are devices, which are placed inside the body to interact with human neurons. They cause a deep brain stimulation in an effort to "reduce the symptoms of various brain-based disorders" [89]. This approach has already proved beneficial. It improved communication skills and cognitive control, and suppressed some movement disorders [90]. Retinal, optogenetic and neural implants can revolutionize the assistive technologies we now use. They synchronize the human brain with AI. So far, these implants have not been intensively used and tested, so their positive impact and contraindications are still unknown. Many research centers extensively explore them and have already delivered the first prototypes. After several years, the futuristic assistive technologies will no longer be a science fiction.

4.9 Conclusions

Artificial intelligence has intensively evolved. It has invented many techniques, which became pervasive and reached a mainstream use. AI has dramatically transformed the world, supporting or replacing many routine activities and assisting people to perform

better. AI powered assistive technologies bridged the communication gap, facilitating even the people with multiple disabilities to access and exchange information in real time. Accessibility wizards of most operating systems, text and screen magnification, text-to-speech add-ons, translation of the text to Braille alphabet and mind-mapping applications have significantly contributed to this success.

The future of education systems, particularly after the pandemic will embrace adaptive learning technologies, replacing the in-person activities with more inventive online activities, which support human communication and the inclusion of students with some impairment.

Although the technology has considerably advanced, the access to sophisticated assistive educational tools is still a privilege of wealthier, predominantly English speaking students. The problem should be solved internationally and nationally.

The international community should unite AI researchers, educationalists and software developers. Pedagogues will suggest to researchers how to invent new and more available solutions that fulfil all the pedagogical and methodological methods, aspects and implications, caring about the content and context [91]. Then, researchers and software developers will transform them into new and more powerful tools. Many free and open FOOS initiatives presented in this paper prove that this ambitious goal can be reached.

National authorities should increase the reach of assistive tools, making them available to all. The order of activities is the opposite from the order of qualitative factors for selecting the tools presented in the introduction of this paper. At first, ministries of education should purchase the software licenses for the tools, providing them to all the impaired students in the country. The second obligation is to localize them, bypassing the language difficulty. Portability will be enabled by the international software developing community, with careful supervision by experienced pedagogues.

The most popular learning management systems (LMS): Blackboard, Canvas, Desire2Learn and Moodle already contain several accessibility plugins based on speech recognition, speech synthesis and voice assistants, reducing the need of additional assistive technologies. In parallel, many universities provide accessible hardware and assistive technologies on campus. Whenever accessible LMS plugins are not sufficient, students have an access to same accessibility software solutions for a very reasonable price.

It is expected that in the near future, new LMS plugins will support the behavioral signal processing [92], enabling technology to understand the emotions of the students and inform the teacher about the emotional state in real time. They will check whether students stay focused during their lessons, or if they are distracted or frustrated. If their interest to attend the lectures is low, they can be forwarded to some virtual reality (VR) [93], and/or augmented reality (AR) alternative, like Google Expeditions and Tour Creator (edu.google.com/products/vr-ar/expeditions/). Google Expeditions is a software platform that offers over 900 VR and 100 AR excursions created in partnership with the most famous museums worldwide.

It is undeniable that AI has a great potential to support and even transform the lives of students with disabilities. This paper tried to prove this claim by presenting many AI driven assistive technologies and their power to overcome the disability barriers. Some researchers have a completely opposite opinion. For example, Smith & Smith think that AI and disability is still "too much promise, yet too little substance" [94]. One of the major arguments supporting this provocative assertion are the ethical concerns of AI systems, which instead of working for the sake of the disabled people, increase their discrimination. They also have an impression that AI at the same time assists and frustrates the disabled people. How right are they? Unfortunately, a lot.

Some assistive technologies, for example: DaVinci Pro HD OCR and OnyxOCR 24 from Table 4.1 and Logan ProxTalker from Table 4.2 are not affordable to students who need them. Hardware, software and operating systems incompatibilities, language obstacles, and particularly the high price of many tools have already been mentioned throughout this paper. Inability of students with motor impairment to get into lecture rooms, incapability to listen the lectures or see the presentations due to hearing and vision impairment, insufficient time to complete the time limited examinations caused by cognition or motion problems are not an exception, on a contrary, they are still a problem in many countries. All these obstacles are related to social disparity [95].

Many students are not capable for independent learning, either because they are incompetent for fully independent life due to some disability, or because they simply strive for human contact and empathy. Online teaching and learning and intelligent assistive systems should complement human-delivered care. During the pandemic, human contacts were kept to a minimum, severely affecting students with cognition or intellectual impairment.

Students with disabilities usually have limited information access. Very few of them are IT savvy [96]. Experienced teachers cope with these problems. Unfortunately, intelligent assistive technologies collect many sensitive data, harming both, students' personal privacy and their medical confidentiality [87]. Behavioral monitoring additionally worsens the problem.

Futuristic assistive technologies might interfere human dignity [97]. Ethical problems embrace: the selection of candidates for neural implants, responsibility of unpredicted reactions, liability for caused dangers, predator's monitoring, potential interference of brain activity and security breaches [97]. It is still too early to find a solution to all these ethical challenges, but they should be taken into consideration as soon as possible.

Carl Sagan wrote: "Every generation worries that educational standards are decaying" [98]. In 2020, traditional education was instantly transformed to online education. Students with disabilities were the most affected by this urgent shift. AI assistive technologies may become the moral agents that contribute most to AI4SG.

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