

Neuroplasticity and Digital Tools in Lifelong Learning: Cognitive Challenges and Opportunities

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Abstract— Neuroplasticity plays a crucial role in lifelong learning (LLL), particularly in supporting cognitive adaptability and resilience in older adults. The integration of digital learning tools has introduced new opportunities for enhancing memory, attention, and cognitive flexibility. This study explores the impact of gamification, adaptive learning platforms, and AI-driven education on neuroplasticity, emphasizing their role in maintaining cognitive functions and fostering engagement. The research examines how digital learning environments, including language apps (e.g., Duolingo), MOOCs (e.g., Coursera, Khan Academy), and virtual simulations, contribute to cognitive stimulation. While these tools provide increased accessibility and engagement, challenges such as digital stress, motivation fluctuations, and information overload remain key concerns. The study further investigates how self-regulation strategies and structured learning environments can optimize digital education for older learners. By analyzing expert insights, case studies, and existing research, this study proposes recommendations for improving digital learning experiences tailored to cognitive aging. The findings contribute to ongoing discussions on lifelong learning, offering strategies to support cognitive health and maximize the potential of digital education for an aging population.

Keywords — adaptive learning; AI in education; digital learning tools; digital stress; gamification; lifelong learning; motivation; Neuroplasticity.

I. INTRODUCTION

In the field of medicine, social work and education today, there are challenges related to the interaction and support of social activity of older people and people with disabilities. These individuals experience various challenges, including physical, mental, social, emotional, cognitive, and visual impairments, as well as difficulties arising from personal and environmental factors, such as social and physical barriers [1].

Why do we include people with disabilities in our scientific review? Because, according to UNICEF's statistical analysis for 2021, there are about 240 million children with disabilities in the world [2]. This number is projected to grow steadily according to demographic trends. Some of these children are already of preschool age and receive financial support. In general, the issue of human ageing itself has a significant impact on the policy of each state, as cognitive ageing leads to an increase in requests for specific assistance and support. And according

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to the Madrid Plan of Action, which aims to address the issue of ageing in the 21st century, we should focus on three areas:

- older people and development;
- preserving health and well-being in old age;
- ensuring a favourable and supportive environment [1].

Addressing these challenges requires attention, and in some cases, education rather than social or medical support provides the best solution. We believe that integrating digital technologies into lifelong learning projects is crucial for maintaining cognitive activity and adaptability in older people and individuals with disabilities. At the same time, it is worth noting that each country is making efforts in its own way to adapt existing laws, rights and regulations to ensure that a person with a disability (physical, mental, cognitive, sensory or emotional) or who is becoming an older person lives without discrimination and is treated as a normal person. This is to ensure that each of them has the opportunity to continue an active social and professional life.

Thus, in most cases today, disability is a general term for impairments, limitations of activity and participation, which refers to the negative aspects of the interaction between a person (for health reasons) and contextual factors (environmental and personal) [3]. Therefore, the search for specific technological solutions becomes a part of support, which includes

- medical services (research using smartwatches and other means of physical condition and neural activity);
- social services (creation of social, financial support and cultural interaction programmes based on the data obtained to involve older people in socially significant events, activities, clubs, physical activity, etc.);
- educational services, which include updating educational programmes, introducing specific courses to improve cognitive functions, introducing new technologies, etc.

While all aspects of inclusion are important, we argue that educational services should take priority. After all, education creates the preconditions for cognitive activity and stable functionality at any age. It allows a person not only to acquire knowledge and master certain skills, but also to form a constant interest and desire for self-development [4]. This, in turn, should ensure constant brain activity, which affects the functioning of the whole organism.

Thus, changes in the educational environment are necessary and inevitable. This is confirmed in UNESCO documents, as education is no longer limited to traditional schooling for children, but is expanding to include lifelong learning [5]. It promotes employability by retraining and upskilling workers in a changing world of work; enables people to master the digital revolution; enables students of all ages to take action to protect the climate; supports health and well-being in communities; helps countries respond to

an ageing society, as the world's population aged 65 and over is expected to outnumber young people by 2050; and promotes tolerance and democratic values in the face of profound social and economic change [5].

This, in turn, directs scientists and practitioners to in-depth research into mental processes and phenomena that affect education and cognition processes that are directly related to inclusion and lifelong learning. That is why the purpose of this theoretical review is to model a basic algorithm for using digital learning platforms, gamification, and artificial intelligence-driven educational tools to stimulate neuroplasticity and maintain the cognitive health of older people.

II. MATERIALS AND METHODS

The main objectives of this review are as follows:

- To analyse scientific research on the impact of neuroplasticity on cognitive ageing.
- To explore the main challenges and barriers to digital learning in older age, considering the potential of neuroplasticity.
- To identify the most effective digital tools for enhancing cognitive functionality among older adults.
- To propose a basic model for ICT-based learning tailored to the neuroplasticity-related needs of older adults.

To achieve these objectives, we employed the following research methods:

- Review of recent literature on neuroplasticity and digital learning.
- Analysis and generalisation of the effectiveness of digital solutions in enhancing cognitive functions.
- An expert survey involving speech therapists, cognitive therapists, and educators on the application of ICT in older adults' education.
- AI-assisted structuring was employed to improve coherence and organisation while preserving the integrity of the original content.

III. RESULTS AND DISCUSSION

A. Neuroplasticity: Cognitive Challenges and Opportunities

Neuroplasticity, a science that has gone beyond biological or medical research (Fig. 1). Of course, one of the developmental questions that scientists are asking themselves is how the brain changes throughout our lives in terms of physiological and neurological indicators. But in the future, these data are proposed to be used to determine typical and atypical development for a certain age, as well as specific neurocognitive disorders and psychopathologies [6] that affect the ability to learn throughout life, maintain an active professional position and social engagement.

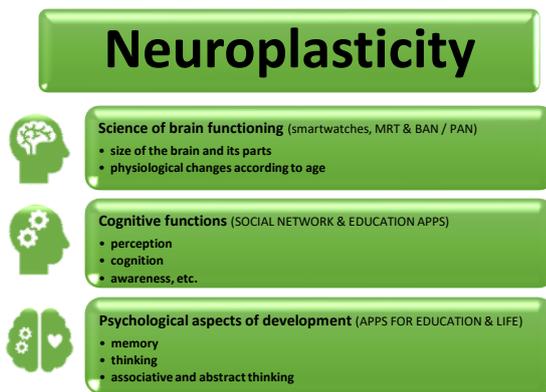


Fig. 1. Neuroplasticity as a scientific field.

The elements of cognitive science within the framework of neuroplasticity allow us to place emphasis on the competitiveness of the modern world. That is, those who have a smart competitive mind and are ready to adapt to complex new situations [7] are in a winning position. That is why we have various brain training programmes or traditional methods such as meditation that stimulate neuroplasticity. We also recognise that a person's effectiveness depends on their unique way of correlating with specific cognitive functions, including the speed of mastering digital skills. Depending on experience, culture, lifestyle, and many other variables, including biological and historical developmental factors [7], we have significant differences in brain functioning. As an example, we can look at how different nationalities and cultures approach the same mathematical problem differently, but we will discuss this in more detail in our next publications.

In general, today this particular part of neuroplasticity cognition includes the study of cognitive functions not only of an individual character, but also of interpersonal (emotion recognition, linguistic communication, etc.) and social (religion, morality, direct behaviour in conflict management, etc.) [7].

The next step in understanding neuroplasticity is the fundamental work of the nervous systems used to train AI today, which is the most important part of learning for the human brain – the association of the first stimulus with the next one that occurs at approximately the same time and the automatic reproduction of the second one when the first one appears [8]. What does this give us? We form neural connections through associations in the world around us, which we perceive. Based on these associations, our brain develops a certain algorithm of actions in a given situation, which becomes stable over time. These processes are easiest to understand through recall, which works even without a real object when there is a set of associations. But over time, this also leads to a decrease in new forms of interaction or algorithms for solving current tasks, both at home and at work. For example, an elderly person needs more time to master modern technologies, while a child born during the period of introduction of this technology seems to absorb intuitive and practical knowledge about its use with the «mother's milk».

Why does this happen? Because memory is mired in countless prejudices and distortions, and the original picture of the event we recorded was influenced by multiple factors. It may sound complicated, but the accumulation of outdated mechanisms for responding to new technological solutions hinders the development of a new algorithm for perceiving and responding to an «unexpected» element. In addition, it is worth remembering those elements that we specifically study or try to erase from our memory [9]. All of this increases the error in cognition and eventually narrows the channels of perception and information processing.

That is why the issue of neuroplasticity as a driving force for change in the focus of technology use allows us to approach the issue of cognitive ageing and the need to learn: to know, to do, to live together, to be [10]. Thus, learning becomes a panacea for overcoming various challenges caused by change. This includes lifelong learning, which is seen as a means of solving the problems of maintaining employability.

The proposed flexible learning is a so-called insider solution for deep transformations of modern society [11]. It can help to stimulate and preserve cognitive abilities, delay the decline in cognitive functions in older people [12]. In this aspect, changes for older people include:

- improvement of cognitive functions, as basic education develops an inquisitive open mind;
- career advancement, which helps to fully develop natural abilities;
- personal growth and fulfilment, enrichment of life related to self-realisation;
- social connections and community involvement, which helps us to make new friends and establish valuable relationships; supports us as active members of society;
- adaptability and resilience, which help us find meaning in our lives and adapt to change;
- opportunities to make the world a better place [12, 13].

B. Digital Tools for LLL

«In the state of flow “the sense of duration of time is altered; hours pass by in minutes, and minutes can stretch out to seem like hours» [13].

If we consider all the challenges facing older people's education, we must also take into account that lifelong learning is about providing a second chance to update basic skills and the opportunity to learn at higher levels [13]. In particular, the process of lifelong learning helps to maintain mental acuity and improve memory, stimulates and enables people to acquire the knowledge, values, skills and understanding they will need throughout their lives and apply them with confidence, creativity and enjoyment in all roles, circumstances and environments [13]. Within the framework of LLL, the following types of learning are distinguished:

- Formal learning, which takes place in an organised and structured context (formal education, apprenticeships) and can lead to formal recognition (diploma, certificate) [13];
- Non-formal learning is integrated into planned activities that are not explicitly defined as learning, but which contain an important element. For example, professional skills acquired in the workplace [13]. The defining characteristic of non-formal education is that it is a supplement, alternative or complement to formal education in the LLL process [15];
- Informal learning is the result of everyday life activities related to family, work or leisure. It is often referred to as experiential learning and is to some extent considered as incidental learning [13].
- Social learning is a relatively new format of learning that scholars have distinguished from informal and non-formal learning, based on the fact that interaction takes place online. In particular, this applies to independent learning activities on the Internet; sharing information and knowledge among peers through online interaction; searching for answers to everyday questions, downloading relevant files [16], watching video instructions or blogs that address these issues, and finding solutions to work issues. And this list, in our opinion, is constantly expanding and supplementing, in particular with the increasing participation and influence of generative AI and neural networks in general. In addition, in this case, students are involved in practices that require active construction of new knowledge and understanding of the processes taking place [11].

All these efforts are aimed at developing a new set of competencies that go beyond the obvious ICT literacy or DigComp: communication, collaboration, social and cultural skills, creativity, critical thinking, problem solving, productivity in a globalised world, learning skills, self-direction, planning, flexibility, risk-taking, conflict management, and a sense of initiative and entrepreneurship [14, 17].

Typically, the goal of modern education set by formal structures is to lay the foundation for lifelong learning and human development, on the basis of which education systems can then expand further educational opportunities [15]. Therefore, a basic learning offer uses:

- synchronous distance learning sessions using virtual classrooms equipped with electronic whiteboards;
 - asynchronous sessions and Web 2.0 tools (podcasts, wikis, chats, forums, blogs, the use of which is also uneven depending on the territorial, economic, cultural or social situation) [11];
 - massive open courses such as Coursera, Khan Academy, EdEra, Prometheus, EDX, Alison, etc.
 - But this is only the first layer of modern technological solutions for education. After all, this type of education and interaction with the next generations of Web resources allow expanding the educational arsenal by
- virtual simulations or interaction environments (OpenSim, AltspaceVR) that promote cognitive stimulation [10, 18];
 - language applications that also support cognitive activity (e.g. Duolingo);
 - learning through blogs, podcasts, and video casts, which have changed the specifics of interaction platforms such as YouTube, Facebook, MySpace, and Instagram [11] by expanding services to provide certified or professional practical content on a particular highly specialised topic.

The next layer of digital education for LLL includes, in our opinion, a number of further and more complex forms of implementation. The first is GBL, or game-based learning, which is based on active user actions and provides a transition from serious games to gamification. The spectrum of GBL ranges from specially designed digital serious games that combine learning objectives in a game universe with some cognitive and visual immersion and gameplay, to gamification as ‘the use of game design elements in non-game contexts’ [14]. Here we can mention training for technical staff of steel mills; the use of simulators and car seats for driver training; online city tours around the world, etc.

The second is the use of artificial intelligence-based tools, taking into account possible risks, such as threats to privacy and security, but with an interest in improving the teaching and learning process [20].

The third, which few people write about and pay attention to, is contextual learning, which works like contextual advertising or «25-frame». That is, in an unobtrusive way, it provides knowledge on one or more subjects while reading fiction or entertainment, watching TV series or videos. The types of information presented can range from the hard sciences to historical facts, religious or cultural features. Of course, the quality of contextual learning often depends on the publisher and author of the content and material. Therefore, any information should be checked, and for this purpose, a person should have a developed algorithm for responding to fake information, i.e., searching for confirmation or refutation of the data received. Today, such a mechanism is being developed as part of media literacy.

Fourth, and in our opinion, in line with social learning, but still related to contextual learning, is the conscious comprehension of processes or events that take place in short entertaining sketches. We often see this type of material today in Facebook's Storify feed, YouTube shorts, or short sketches of various events and situations on TikTok. However, according to our observations and interviews, this type of digital education is used by a small percentage of viewers. An example of such use is watching videos of car accidents, which a driver watches to work out an algorithm of actions to avoid a collision. This method is psychologically based, because in this way the brain perceives a dangerous moment in the safest possible conditions. And, subject to repeated stimulation of such an algorithm for preparing for a non-standard situation, the

body automates the proven algorithm for reacting to events in real time with maximum efficiency.

An additional stimulus for any of the previously described areas of education is music and physical activity. Why? Movement is inseparable from consciousness or, perhaps, controls it, and in different age periods, these movements are different. In old age, movement stimulates oscillations in the hippocampus and cerebral cortex, which increase synaptic plasticity, improve communication between brain areas, and optimise brain function. In other

words, the connection between the brain and the body is bidirectional: oscillatory rhythms in the brain control movement, and movement controls oscillatory rhythms. When the physical body tunes in to external (e.g., music) or internal (e.g., breathing) rhythms, these rhythms engage the brain areas associated with the external world (auditory and sensory) and subsequently engage other, more internally focused brain areas (motor, cognitive, and emotional) [21].

TABLE 1. DIGITAL TOOLS FOR LLL

DigCom p level	Essential digital tools				
		Digital engagement and solutions		Benefits	Challenges and barriers
I	Formal learning	synchronous distance learning sessions using virtual classrooms	Zoom, Google Meet, To Go, Microsoft Team, etc	complex issues here and now, intuitive format of interaction (taking into account the number of years of adaptation and adjustment of the educational process to online education)	level of technical support, organisational readiness of the teacher
II	Non-formal learning and informal learning	asynchronous sessions	Moodle, MOOCs and other state-supported platforms that can be used both synchronously for classroom tasks and asynchronously	Choosing a highly specialised topic that meets the interests of the individual or the needs of the employer	Uneven provision depending on the territorial, economic, cultural or social situation
		Web 2.0 tools	Wiki, Blogs, e-mail and instant messengers, open source office applications in the cloud, file sharing, etc	Accessibility, relatively easy format of use	
		massive open courses (both narrowly focused on a particular speciality and with a wide range of topics and directions in various fields of science)	Coursera, Khan Academy, EdEra, Prometheus, EDX, Alison, etc.	Accessibility, wide range of topics, possibility of certification, reliable primary sources	Availability of appropriate digital competence, language barriers, technical implementation
		GBL (game-based learning)	Language applications or applications for the development of attention, memory and logic (duolingo, various mahjongs, go, chess, sudoku, tetris, etc.)	Accessibility, ease of implementation	Availability of appropriate digital competence
		simulators (sports, racing, flight simulators, workflow simulators ats4, etc.), OpenSim, Altspacvr		Authenticity of facts and proximity to reality	Complexity of implementation even with an intuitive interface
III	Social learning	Forums and specialised platforms	for example ReserchGate, Mendeley for scientists, GitHub for IT professionals, etc	Diversity, accessibility, choice of the best answer to a question	The inability to be sure of the reliability of information, even if it is a "trusted" platform the need to seek confirmation of the reliability of facts and information
		Thematic Blogs, podcasts and video casts on YouTube, Facebook, MySpace and Instagram, video diaries etc			
IV	Learning based on AI models	ChatGPT, OpenAI, Copilot, generative AI from Adobe, various third-party applications based on them that supplement, change video, audio or other elements of audiovisual art		Ease and intuitive usability, accessibility	Threat to privacy and security, the need to verify information
V	Contextual learning	The 25th Frame. The Subliminal Message – presentation of subject knowledge in the format of fiction or entertainment, TV series or videos		Unobtrusive format of material presentation, accessibility and interest of the individual due to the relevance of the basic information to his or her interests	Author's vision or publishing policy that requires verification of the information offered

This involvement creates increased synchrony (i.e., increased power and coherence) between brain areas, contributing to the enhancement of neurobehavioural effects in sensory, motor, cognitive, social, emotional, rhythmic and creative brain areas, which is one of the conditions for maintaining cognitive function and preserving brain neuroplasticity [21]. This, in turn, affects the brain's ability to learn and change itself according to the situation. These changes include: growing new neurons; changing the distribution and location of neurons; modifying new synaptic connections between existing neurons [22].

Below is a summarised list of the digital tools that we believe have the greatest impact on cognitive functioning and can be used for LLL.

Each proposed solution has both advantages and disadvantages for the organisation of LLL. However, the main advantages of each type of training to support the cognitive functioning of older people are

- accessibility, ease of use, intuitive interface;
- maximum approximation to the reality of the process of information assimilation;
- diversity, accessibility, the ability to choose the best answer to a question [23];

- the ability to solve complex issues here and now;
- personalisation and relevance to the interests of the individual or employer. Interest is a crucial motivator for adult learners, creating a desire to participate in learning activities without expecting any external rewards [24];
- formal courses ensure the reliability of facts and information;
- flexibility of learning and the ability to learn at one's own pace;
- in some cases, the possibility of obtaining certification;
- nonobtrusive presentation format that stimulates interest;
- the use of adaptive algorithms for a personalised learning process.

Despite a number of advantages, we should note that each type of training offered to older people has its drawbacks. Namely:

- technical and organisational difficulties in providing the types of training offered for both teachers and students;
- low or no digital competence, and in some cases language barriers;
- lack of government initiatives to teach digital literacy to older people and/or insufficient support for younger generations in explaining complex technical aspects;
- the inability to be sure of the authenticity of information, especially on informal educational platforms, which leads to a constant need to verify it;
- the author's vision or publishing policy, which may distort the content and require additional analysis.

In some cases, privacy and security risks, including the possibility of personal data leakage or the use of unreliable platforms, are also a deterrent to organising LLL.

But the main message is: learning a new language or using a new app for communication or other purposes should be a solution for an older person to continue their social and professional life..

C. A Model of Neuroplasticity Stimulation by Digital Tools

According to our results, we can develop a model for stimulating neuroplasticity and maintaining the cognitive health of older people using modern technologies (ICT), which is presented below (Fig. 2).

We do not claim that this model is the only correct or sufficient for further development and refinement of the concept of lifelong learning. However, the proposed model allows us to consciously combine commonly accepted educational processes and integrate learning processes that arise under the influence of expanding technological solutions.

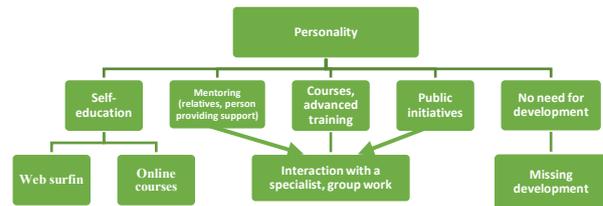


Fig. 2. A model of neuroplasticity stimulation by digital applications in the framework of LLL and personality interests.

In addition, this model will serve as a reminder of the need to adapt digital tools to the cognitive characteristics of older people. Taking into account the need to simplify and provide an intuitive interface of educational applications, platforms, materials for people with different levels of digital literacy. Also, ensure the availability of a facilitator, mentor, or training of family members in the basics of facilitating the acquisition of digital competencies by older family members. This will improve not only cognitive brain functions by providing the neuroplasticity necessary for an active life, but also reduce emotional, psychological and digital stress in the process of using ICTs.

IV. CONCLUSIONS

This paper considers the impact of neuroplasticity on cognitive ageing. We analysed the main benefits, challenges and barriers of digital learning environments for improving memory, attention and cognitive flexibility. We found that even though digital impact depends on the interpersonal and social communication characteristics of an older person, the most effective solutions include individual learning paths and interest-based digital tools. This has allowed us to create an ICT-based learning model that takes into account the adaptability of software to the cognitive needs of older people, provides optimal workload and minimises barriers to use.

In general, digital technologies implemented and complementing the process of lifelong learning are effective means of supporting the cognitive health of older people. Therefore, in our opinion, it is necessary to continue to introduce adaptive platforms that take into account the value of using and developing neuroplasticity, open access to learning resources for the development of digital skills in older people.

The results obtained may be useful for developers of various digital applications, teachers and curriculum developers, social workers, and researchers in the field of cognitive science and education.

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