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Generative AI as a Cultural Phenomenon in the Digital Transformation of Education

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Abstract. The paper explores the transformative impact of Generative AI on education, emphasizing a comprehensive cultural shift. A three-dimensional model of culture, encompassing spiritual, social, and technological components, serves as a framework for analyzing this shift. Traditionally, education has emphasized social culture, reinforcing societal norms. However, the rise of Generative AI introduces a need to balance this with spiritual and technological components. Spiritual culture, defined as 'Existential Self-Awareness,' fosters creative freedom, allowing learners to explore their identity and values. Social culture is undergoing significant changes due to 'Generative Socialization,' as AI agents like chatbots create new interactions between teachers, students, and AI, fostering novel forms of collaboration and communication. Technological culture, once merely instrumental, has now become epistemological, generating new knowledge through human-AI interaction, described as 'Epistemological Technological Culture.' Using the example of the constructionist approach to learning, this paper demonstrates how Generative AI is changing educational practices, providing opportunities for personalized learning and transforming the traditional dynamics of classrooms. This shift compels educators and students to adapt to a new educational environment where AI becomes a collaborative partner, fundamentally rethinking roles, the process of knowledge acquisition, and human self-perception within the educational system. This study provides a framework for understanding and adapting to the transformative potential of Generative AI in education.

Keywords: Artificial Intelligence · Culture · Education · Constructionism

1 Introduction

The recent emergence of Generative Artificial Intelligence (Generative AI) has become a significant event, profoundly impacting many aspects of societal life. This technology has practical and fundamental consequences due to its qualitatively novel nature. Generative AI is not merely a long-awaited step in the development of artificial intelligence but a new and previously unknown technology, the consequences of which, when integrated into everyday life, remain largely uncertain, evoking both admiration and concern. However, the transformative impact of this technology on life has yet to be realized as evidenced by numerous projects where Generative AI is viewed merely as a convenient

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tool for solving everyday tasks. A prime example of this approach is the field of education, where this technology is being actively adopted to enhance the existing educational system. At the same time, there are serious reasons to consider Generative AI as a technology that transforms the processes of human cognition, entailing epistemological and self-conception shifts. Generative AI represents one of the "powerful new cultural technologies" that can be compared to such technologies as language, writing, printing, the Internet, etc. [1]. Unlike traditional rule-driven, classic algorithms-based technologies, it operates using pre-trained models, machine learning, and big data processing, exhibiting an intelligent like behavior that Kelly aptly described as "alien intelligence" [2]. These new mechanisms are already causing tectonic shifts in various spheres of human culture, including education. Consequently, profound changes in the educational system are called for.

This work is dedicated to studying the role of Generative AI in education. The paper addresses the challenges and issues associated with the widespread adoption of this technology, which represents a fundamentally new element in the educational system. The central premise of our research is that Generative AI is so novel and unique that its emergence necessitates the transformation of existing educational practices and structures.

To study and justify the need for such transformations, we employed a comprehensive cultural approach. This approach is based on a three-dimensional model of culture, which encompasses spiritual, social, and technological components. We consider the culture of education as a subspace of human culture, offering a holistic view of the need for transformation in education driven by the emergence of Generative AI.

The study shows that within the educational system, one component of culture—social culture—has primarily developed. Educational practices have historically focused on shaping and reinforcing social norms, as well as preparing individuals to function effectively within society. Meanwhile, the technological and spiritual components of educational culture have remained in the background, playing only a secondary role. In the era of Generative AI, this one-sidedness becomes insufficient and even detrimental, hindering the educational system's ability to adapt to the challenges and opportunities of this new technological reality.

This study examines and demonstrates the changes occurring in each cultural subdomain under the influence of Generative AI. These changes affect the foundations of our understanding and organization of the educational process.

2 Three-Dimensional Model of Culture

Our study builds on a previously established three-dimensional model of human culture [3], extending its application to education as a cultural phenomenon. As illustrated in Fig. 1, the cultural space is defined by three axes: knowledge, values, and regulatives.

The axes of the cultural space have both qualitative and quantitative meanings. In terms of qualitative meaning, each point in the cultural space represents a vector $V = (X, Y, Z)$, where:

- $X =$ knowledge $[0,1]$.
- $Y =$ values $[0,1]$.

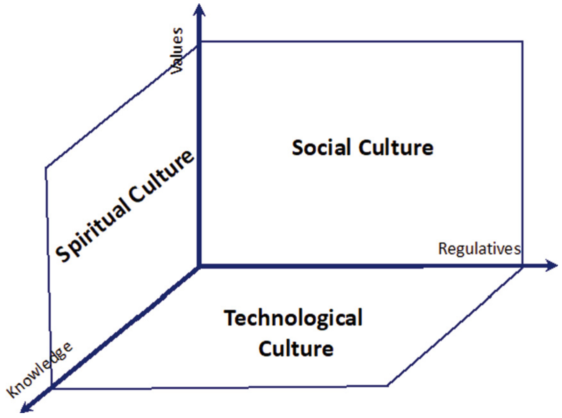

Fig. 1. Three-dimensional model of culture.

- Z = regulations [0,1].

For example, Academic Culture might be represented by the vector V = (1, 0.8, 0.9), indicating:

- High knowledge (X $\approx$ 1).
- Strong educational values (Y $\approx$ 0.8).
- Strict regulations (Z $\approx$ 0.9).

In contrast, a more informal culture might be represented as V = (0.2, 0.5, 0.3), indicating:

- Basic knowledge (X $\approx$ 0.2).
- Mixed values (Y $\approx$ 0.5).
- Relaxed regulations (Z $\approx$ 0.3).

This vector representation quantifies key differences between these cultural phenomena in the educational space.

The three pairs of axes in the cultural space form distinct planes, each representing a unique dimension of human culture. The plane defined by the knowledge and values axes represents spiritual culture. The intersection of the values and regulatives axes delineates social culture, while the plane between the regulatives and knowledge axes corresponds to technological culture.

Within this cultural space, the facet of spiritual culture is often the most influential in shaping daily life. Spiritual culture embodies the cognitive and value-oriented aspects of the cultural space and encompasses elements such as religion, art, and philosophy. What distinguishes all forms of spiritual culture is their emphasis on integrating knowledge and values.

Another significant aspect of the cultural space is social culture, which plays a crucial role in governing social relations and interactions within society. It is located along the values and regulatives axes and comprises ethical, legal, and political dimensions. These aspects of culture mirror societal values, ideals, and normative behaviors, collectively referred to as social culture.

Within the cultural space, the facet of technological culture is situated within the domains of the knowledge and regulatives axes. In its broadest sense, technological culture pertains to the mastery and processing of various artifacts, performance, production, and the design of diverse creations. Knowledge and regulatives stand as crucial and indispensable components of technological culture, with values assuming a secondary role.

3 The Culture of Education in the Generative AI Era

To define the unique culture of education in the era of Generative AI, we shall begin with a brief overview of the general properties characterizing each facet of the cultural space.

Spiritual Culture:

1. Non-utilitarian Essence. Unlike technological and social cultures, spiritual culture is inherently non-utilitarian. It exists in a realm separate from the practicalities of everyday life, focused on the 'joys of the spirit'—beauty, knowledge, and wisdom. Spiritual culture is pursued not for material benefit but for intrinsic fulfillment, embodying a form of engagement that transcends utilitarian concerns.
2. Creative Freedom. Spiritual culture offers unparalleled creative freedom. It is liberated from the constraints of utilitarian and practical considerations, allowing the imagination to soar beyond the bounds of reality. This creative freedom is evident in ancient myths, religious practices, and the arts, where the spiritual realm provides an expansive canvas for human expression and the creation of beauty and meaning.
3. Richness of the Spiritual World. Creative activity within spiritual culture gives rise to a unique and inimitable spiritual world, shaped by the power of human thought. This world is richer and more diverse than the material world, encompassing both real and imagined phenomena. Though grounded in fictional representations, the spiritual world operates according to its own laws and exerts a profound influence on human life, shaping perceptions, beliefs, and values.
4. Sensitivity and Vulnerability. Spiritual culture is the most sensitive and responsive facet of culture, continuously in motion and in tension. Its openness to external influences renders it both dynamic and vulnerable, making it susceptible to shifts in societal values, ideologies, and external pressures. This sensitivity is a double-edged sword, contributing to both its richness and its fragility.

Social Culture:

1. Collective Realization of Values. While spiritual values can be pursued individually, the values of social culture are inherently collective. Social culture manifests through the interactions between individuals within a society, encompassing ideals such as mercy, equality, humanity, law and order, democracy, and civil liberties. These values can only be realized through social connections and collective efforts, requiring a shared commitment to societal norms.

2. Pragmatic Implementation. The products of social culture are designed to be implemented in 'real' life. Unlike the internal and often abstract nature of spiritual culture, social culture is outward-facing, aiming to shape societal behaviors, laws, and ethical codes. Its values and ideals are not just theoretical; they are intended to guide and regulate the conduct of individuals within society, ensuring the smooth functioning of social systems.
3. Normative Framework. Social culture is fundamentally normative, encompassing values, regulations, norms, and rules of behavior. These norms are enforced through social mechanisms such as public opinion, legal systems, and state institutions. While spiritual culture may inspire ideals, social culture translates them into actionable standards that govern social interactions, ensuring the stability and cohesion of society.

Technological Culture:

1. Instrumental Focus. Technological culture is distinct in its focus on the 'how' rather than the 'why' of cultural activities. It is concerned with the methods and tools required to achieve specific goals, evaluating technical parameters such as efficiency, precision, and strength. Unlike spiritual and social cultures, which are oriented toward values and ideals, technological culture is primarily instrumental, serving to an end rather than an end in itself.
2. Utilitarian Nature. Technological culture is inherently utilitarian, often existing in tension with the non-utilitarian nature of spiritual culture. The uneven development of cultural dimensions leads to competition between technological and spiritual values, with technological culture frequently being prioritized in contemporary society. This prioritization can result in the colonization of spiritual values by technical ones, reinforcing consumerist tendencies and undermining the depth and richness of spiritual engagement.
3. Subordinate Role. Despite its utilitarian focus, technological culture plays a subordinate role concerning spiritual and social cultures. It provides the tools and means necessary for the realization of broader cultural goals, but these goals are defined outside the technological realm. The progress of technological culture must be evaluated and controlled through values and principles rooted in spiritual and social cultures, ensuring that technology serves the greater good rather than becoming an end in itself.
4. Universal Applicability. Technological culture has become a universal and indispensable aspect of all cultural activities, particularly in developed countries. Regardless of their field of work, cultural practitioners must be familiar with the technologies that underpin their practices, making technological literacy a prerequisite for participation in contemporary cultural life.
5. Evolution from Mysticism to Rationality. Historically, technological culture has evolved from mysticism to rationality. Since the 17th century, scientific and technological advancements have gradually replaced mythological and religious explanations of the world. Today, technological culture is grounded in technoscientific rationality, which, while not superior to spiritual beliefs, plays a critical role in reshaping almost every domain of contemporary culture. This rationality underpins the ongoing transformation of cultural practices, making technological culture a driving force in the evolution of society.

Historically, education has developed as a social institution with one of its primary objectives being the formation of citizens. [4] This has inevitably left a significant mark on education as a cultural phenomenon. Although humanity has cultivated other forms of culture alongside social culture, education has remained predominantly focused on social orientation. Educational institutions have concentrated on transmitting knowledge, norms, and values that align with social culture. However, spiritual culture, which deals with deep meanings, purposes, and existential questions, often remains outside the education system. Regarding technological culture, the situation is less critical but still requires clarification. The utilitarian nature of technological culture fits easily within the traditional educational framework, where technology is primarily viewed as a tool. However, this limited perspective restricts the development of technological culture, especially when it comes to digital technologies.

Before delving into the cultural analysis of education in the Generative AI era, it is necessary to highlight the key areas where Generative AI is applied in education. Generative models, such as GPT (Generative Pre-trained Transformer), have the capability to generate text, audio, images, and other data by learning from extensive volumes of information.

In the educational context, this opens several significant avenues:

1. Personalized Learning. Generative models can create individualized materials for students, considering their knowledge level, interests, and learning style.
2. Content Creation. Generative models can assist in developing educational content, including textbooks, assignments, tests, and even interactive educational applications.
3. Optimization of Learning Processes. Generative AI can analyze learning data, provide feedback, and suggest improvements for educational programs and teaching methods.
4. Support for Educators. Generative models can serve as assistants to educators, offering recommendations for individual student support and the creation of teaching materials.

In the following sections of this chapter, these and other manifestations of Generative AI in education will be examined as cultural phenomena within three distinct categories: social, spiritual, and technological cultures.

3.1 Social Culture of Education in the Generative AI Era

We will begin with the social culture of education, which, as previously noted, has always been foundational and has thus responded most actively to the emergence of Generative AI.

A distinctive feature of today's social culture is the emergence of AI agents, such as chatbots like ChatGPT, which have entered our lives and become active participants in human intellectual activity. We are witnessing an unprecedented phenomenon—introducing and integrating new entities, not humans, into human society. These agents, on the one hand, are 'alien,' lacking human consciousness, but on the other, they seamlessly integrate into our everyday interactions, becoming almost 'one of us.' This duality highlights the dialectical nature of our relationship with AI: they are simultaneously 'us' and 'not us,' evoking Hegelian philosophical categories of unity and the conflict of opposites.

This tension leads to the emergence of new forms of social interaction and ethical norms concerning AI. It compels society to reconsider its understanding of ethics and morality in the context of interactions with non-human agents, fostering innovative approaches to the evolution of social culture.

The response to the above phenomenon is reflected in the widespread public discussions surrounding ethical issues, questions of evaluation, authorship, regulation, and the potential dangers associated with AI. It is important to note that these discussions have become a central topic, attracting the attention of scholars, educators, and the public [5, 6]. At the same time, the social aspects of Generative AI being discussed are merely manifestations of the profound changes occurring in the social culture of education. The essence of this culture is undergoing transformation, particularly in areas such as teacher-student relationships, teaching processes, and knowledge assessment.

In the context of Generative AI, the roles of teachers and students undergo significant transformation, altering the nature of their interactions and the assessment process. The content being taught and learned assumes new forms, necessitating a re-evaluation of traditional educational approaches. Both educators and students, adapting to this evolving landscape, must reconsider their roles, methods, and expectations. As a result, the focus extends beyond ethical and social concerns, encompassing fundamental changes in educational practices themselves.

One of the most notable trends in the Generative AI era is the transformation of human interaction, which has become a defining feature of the social culture of education. Generative AI enables the creation of new and previously unattainable forms of communication and collaboration, playing a pivotal role in reshaping the social dynamics within educational settings.

The advent of Generative AI ushers in a profound transformation in education, challenging the very foundations of teaching, redefining the role of the teacher, altering the essence of knowledge, reshaping the identity of the student, and, perhaps most crucially, reconfiguring the intricate relationships that bind them all together [7]. Teachers are now finding themselves working alongside AI as a teaching assistant or co-instructor, while students increasingly view Generative AI as a training partner. This shift, from technology serving as a traditional tool to becoming a collaborative partner, represents a fundamental change in the role of educational technology. Generative AI is not just shaping and transforming the social settings of education; it is becoming an integral part of the educational social culture itself.

This technology transformation into a teammate, where machines exhibit human-like behaviors [8], is accompanied by the emergence of new types of entities—human-AI collaborations—known as centaurs or human/AI cyborgs. While Kelly uses the terms centaur and cyborg interchangeably [2], Dell'Acqua et al. suggest that the two models should be differentiated. The centaur approach involves a "strategic division of labor between humans and machines closely fused together," with responsibilities allocated "based on the strengths and capabilities of each entity." In contrast, cyborg behavior implies intertwining human efforts "with AI at the very frontier of capabilities," alternating responsibilities at the subtask level [9].

In both models, the Bricolage approach to knowledge is becoming more dominant, shifting from a predefined linear method to a more intuitive, creative, and art-like approach. In this context, the teacher's mission is to help students discover and harness their inner curiosity, passion, and motivation, enabling them to bring their unique creative voices to life as Bricoleurs. This approach allows students to explore and integrate knowledge from various domains while engaging in trial and error as part of the learning and creative process. In this evolving role, teachers act as mentors, guiding students to discover and cultivate their individuality in tandem with Generative AI. They help students identify what distinguishes them as humans and lead them along personalized learning paths. Teachers should also facilitate discussions, collaborative work, and the exchange of ideas among students, enhancing the human factor and the unique characteristics of human connections and collective thinking. This aspect is crucial in a world where interactions with machines are commonplace as part of the ongoing quest to define what it means to be human in a Generative AI-abundant world.

This leads to a fundamentally different educational social landscape, characterized by new social conditions, procedures, roles, and functions for students, educators, and technologies. It also introduces new challenges and legal statuses for both Generative AI and AI-generated content. The changes that Generative AI will bring to the field of education are highly significant. Both teachers and learners must adopt new roles and functions, and educational institutions must adjust their approaches and redesign the educational process, including assessment procedures [10–13].

Generative AI is shaping new social norms in education by enhancing collective experiences through AI collaboration, transforming traditional classroom interactions into a new AI-infused reality. This form of socialization emphasizes flexibility and adaptability within a rapidly evolving technological environment, integrating new technologies into established social frameworks while also challenging and redefining them.

We refer to the social culture of the Generative AI era as the culture of 'Generative Socialization,' defined as the process through which individuals engage in social learning and interaction, shaped by the presence and influence of Generative AI. In the context of education, it reflects the democratization of knowledge creation, where AI becomes an active participant, transforming traditional hierarchies between teachers and students. This concept emphasizes collaborative intellectual engagement with AI, fostering more personalized, dynamic, and inclusive social experiences. Generative Socialization marks a shift from standardized, one-way knowledge transmission to a co-creative, multi-directional learning process, where both human and AI contributions play essential roles.

3.2 Spiritual Culture of Education in the Generative AI Era

Personalization became a crucial component of education at the outset of the digital age [14]. However, in the era of Generative AI, this reaches a new level. Interaction with Generative AI is not merely an informational exchange; chatbots become interlocutors for students, capable of generating content that is deeply tailored to their needs. Knowledge is generated in a form that reflects the student's individual way of thinking, contemplating, and articulating their questions. Over time, the chatbot increasingly becomes a personal interlocutor, serving as a kind of 'alter ego' for the student.

This interaction pushes students beyond the traditional analysis and comprehension of material, engaging them in a more personalized creative process. As a result, the spiritual culture of the student is developed throughout the learning experience. This innovative personalization also extends to the selection and creation of educational content.

Spiritual educational culture can be viewed as a combination of two components, i.e. educational content and learning viewed as an ability to process information and knowledge. Educational content shapes knowledge and values, while learning refines a person's individuality. Both components demonstrate an epistemological transition in the Generative AI era (in knowledge and the formation of self-identity), which can be described using the term 'Bricolage', presented by Claude Lévi-Strauss [15] and later on adopted by Turkle and Papert [16] in their research on programming styles. Bricolage refers to an epistemology that contrasts with the traditional, formal approach to programming taught in universities, which was based on "a rule-driven system that can be mastered in a top-down, divide-and-conquer way." The Bricolage approach they identified was different; it was "marked by a desire to play with the elements of the program, to move them around almost as though they were material elements—the words in a sentence, the notes in a musical composition, the elements of a collage" [16]. In the Generative AI era, this epistemology is becoming relevant to everyone, not just programmers. It characterizes how knowledge is constructed, how insights are gained, and how we create and interpret meanings in our experiences through interactions with Generative AI. These interactions enable us to piece together endless knowledge domains, and 'play' with the data as if it were material elements. In this sense we are moving away from the traditional positivist approach to knowledge, into a more adaptive, fluid, personalized Bricolage approach [17].

Generative AI brings about an addition to the brilliant observation by Turkle and Papert of the Bricolage epistemology enabled by computers [16]. Today, interactions with Generative AI impact our self-identity and sense of self. As a rapidly evolving technology that continuously exhibits human-like capabilities, Generative AI requires that both children's and adults' self-conceptions be adapted and reshaped accordingly. The question of who we are as humans and what makes us human is an inherent part of interacting with Generative AI and is present, whether explicitly or implicitly, in people's everyday experiences. This is a constant question, the answers to which are likely to continue evolving. This requires a constant quest for self-identity, which becomes more fluid and flexible, resembling a Bricolage approach. The constant construction and deconstruction of self-identity is, in a way, like a Bricoleur's crafting of self-identity. This process of individualization and creative reflection supports spiritual growth, making it more interactive and personalized than ever before.

To address these challenges, children need to be equipped with philosophical foundations and basic principles that will enable them to think critically and reflect on ontological, epistemological, and existential issues, which are increasingly integral to living in the digital world. This aspect of the 'Child Philosophers', highlighted by Turkle in her studies of children's interactions with computers [18], is evident in both the educational content and the learning component that shapes one's individuality. It also influences the teachers' role within the sphere of social culture, as discussed in the section devoted to social culture.

We refer to the spiritual culture of the Generative AI era as the culture of 'Existential Self-Awareness,' defined as a profound form of self-reflection and personal growth arising from an individual's interaction with AI technologies. This concept encompasses the exploration of one's identity, values, and life purpose, facilitated by AI's ability to generate personalized experiences, insights, and perspectives. It marks a shift from external knowledge acquisition to an internal process of self-realization, where individuals engage with AI not merely as tools but as partners on a journey toward deeper existential understanding and spiritual development.

3.3 Technological Culture of Education in the Generative AI Era

As previously mentioned, in the socially oriented education system technological culture traditionally played a supporting role and remained on the periphery of the overall development of educational culture despite its significant role. However, in the current technological context, this situation has substantially changed. We have entered an era of developing a technological culture of education. This shift is primarily due to changes in how people perceive technology.

Below are three fundamental principles underlying these changes.

1. Rejection of a purely instrumental view of technology. Traditionally, technologies in educational were viewed solely as tools to enhance the learning process. Such an approach was justified when technologies primarily served auxiliary functions. However, in the context of Generative AI, this instrumental view is outdated and counterproductive. Generative AI is not merely a tool; it becomes an active participant in knowledge acquisition, contributing to the revelation of self-conception and offering opportunities for interaction with a fundamentally new entity beyond traditional notion of machines. Applying generative AI within outdated instrumental frameworks only reinforces old educational paradigms, hindering the necessary transformations in the era of new technologies.
2. Rejection of perception of technology as a 'black box'. Generative AI operates on principles that differ significantly from both human thinking and conventional computational thinking. We are unfamiliar with the situation in which a certain level of literacy in AI functionality becomes fundamentally important, and the 'black box' principle ceases to be effective. Such a situation has arisen precisely because we are dealing with a completely new form of information technology, unprecedented in human experience. It is essential to recognize that AI represents a distinct entity, and its processes require a new level of understanding and interpretation. Rejecting the perception of AI as a 'black box' is crucial for effectively integrating the technology into the educational environment, presenting both a challenge and an opportunity for growth.
3. Perception of Generative AI as an epistemological technology. Generative AI, a transformative force in the era of rapid technological advancement, redefines our approach to knowledge creation. Unlike traditional tools such as the Internet, databases, and computing, which primarily facilitate accumulation, organization, and transmission

of knowledge, generative AI actively generates new knowledge. This unique capability shifts it from being a traditional ontological technology, which supports existing cognitive processes, to an epistemological technology that fosters the creation of new ideas, texts, images, and scientific hypotheses. Generative AI not only expands our understanding of the world but also transforms it, ushering in a new era of perceiving and comprehending reality.

It is essential to provide learners with AI principles that help them understand the nature of human-AI interactions and how to leverage them fully. To achieve this, education should incorporate both human learning and perception mechanisms and the foundational principles of machine learning and artificial intelligence. This will require a shift in teaching methods starting from elementary school moving away from traditional ontological approaches toward innovative, epistemologically oriented teaching [19]. By understanding these concepts, learners will be better equipped to engage in the knowledge co-creation process with self-reflection and critical thinking, while also addressing the limitations and ethical considerations of the partnership between humans and Generative AI. This transformation represents a shift toward a new technological culture, where AI becomes integral to knowledge acquisition, fundamentally altering its structure and dynamics.

We refer to the technological culture of the Generative AI era as an 'Epistemological Technological Culture,' which emphasizes how technology is understood and engaged with, transcending its traditional role as a tool or 'black box' to being recognized as a co-creator of knowledge. This concept underscores the integration of AI in shaping human understanding and decision-making, where technology not only assists in problem-solving but also actively generates insights and shapes epistemic frameworks. In this culture, the boundaries between human and technological knowledge production blur, fostering a deeper, more interactive relationship with AI. This marks a shift away from instrumentalism toward an era in which technology plays an active role in epistemological exploration and intellectual discovery, influencing how knowledge is conceptualized, created, and shared.

To summarize, our vision of the culture of education in the Generative AI era is graphically represented in Fig. 2, which builds upon the original three-dimensional model of culture depicted in Fig. 1. The spiritual, social, and technological dimensions of culture are defined as Existential Self-Awareness, Generative Socialization, and Epistemological Culture, respectively.

4 Constructionism in the Generative AI Era

In this section, we examine how education and its culture are being transformed through the evolution of one of the most prominent learning approaches developed at the onset of the digital age: constructionist theory. We have selected constructionism as a case study because, from its inception, this approach has underscored the need for significant changes in education in response to the digital era. The key trends of constructionism in the digital age were explored by Levin and Tsybulsky [20]. In this paper, we apply a cultural studies approach to explore constructionism in the context of Generative AI. We

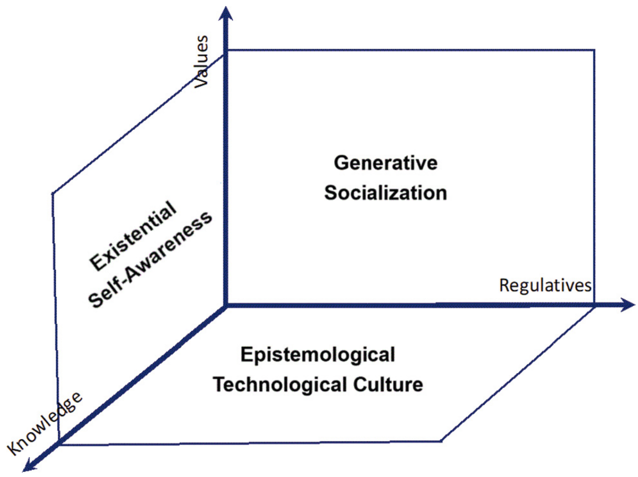

Fig. 2. Three-dimensional cultural model for education in the Generative AI era.

hypothesize that analyzing the culture of constructionist education can most effectively reveal the key transformative trends reshaping education in the era of Generative AI.

4.1 Social Culture of Constructionism in the Era of Generative AI

The concept of democratization within constructionism has undergone several critical stages of development, beginning with the early ideas proposed by Seymour Papert [21]. At the core of constructionism lies the concept of democratizing education, which initially meant that personal computers allowed students to step outside the boundaries of the traditional educational system and the control of the Ministry of Education. Computers became a tool for independent creativity and learning, marking the first step toward democratizing educational processes within constructionism. For the first time, students could work on projects and solve problems without strict external oversight, expanding the boundaries of independent thinking and action. According to S. Papert, the democratization of learning is based on providing students with access to knowledge and technology and, through this, realizing their creative abilities. Papert saw the computer as a tool and a new educational environment that allowed the student to express himself without depending on the teacher's instructions or the educational system. In his paper *Perestroika and Epistemological Politics,* Papert compared the traditional hierarchical educational system with the political system of the Soviet Union before Perestroika, arguing that the same fate awaited the education system [22]. Thus, democratization has emerged as a defining principle of the social culture of constructionism.

With the development of the internet and social networks, the next stage emerged—hyperconnectivity, which strengthened the democratization process. The ability of learners to connect and share content globally, beyond traditional educational frameworks, became a defining feature of this phase. The constructionist paradigm in education took on new forms through online communities where students could learn from each other, creating and sharing knowledge without formal institutions' mediation. Hyperconnectivity pushed constructionism toward more democratic approaches, softening hierarchies and opening access to knowledge and creative opportunities for broader segments of society.

However, the most significant stage of democratization within constructionist education is in the era of generative AI. We are witnessing a radical shift in how technologies are perceived—not just as tools for accomplishing tasks but as equal participants in the educational process. Generative AI becomes an active agent in creating intellectual content, and students interact with it not within a hierarchical 'human-machine' system but on equal footing, treating AI as a 'dialogue partner' and co-creator. In this context, technology is no longer a subordinate means but a partner in the educational process. With the advent of Generative AI, democratization moves to the next level, as discussed in this section. Generative AI is not just a technology—it is a new 'inhabitant' of our planet, a new agent with which students can interact at a level comparable to interaction with a person. This AI has become an active participant in the educational process, Papert's 'object-to-think-with' [21], with whom it is possible to collaborate on a deeper level than before. Unlike previous digital technologies, such as computers and the Internet, Generative AI changes the very nature of the interaction, which leads to a novel and unprecedented level and nature of democratization.

This transformation is closely linked to the ideas of the influential French philosopher Gilbert Simondon, who advocated rethinking the hierarchical structure of human-technology interactions. Simondon emphasized that the traditional view of technology as a subordinate tool no longer reflects reality. He wrote about how people learned to treat animals with respect and recognized equality between men and women and then between different races. This is a rejection of old systems of control and a transition to a new form of respectful interaction with technology as an active participant in human life [23]. His ideas are particularly relevant in Generative AI, where technologies become part of the cognitive process, not just objects of manipulation.

It is important to note that these ideas resonate with the three classes of instruments distinguished in Ancient Rome: the articulate or vocal *(instrumentum vocale),* comprising the slaves; the inarticulate or semivocal *(instrumentum semivocale),* comprising the cattle; and the mute *(instrumentum mutum),* comprising the vehicles (technology). [24] This classification reflects how Roman society viewed inanimate technological tools, alongside humans and animals, as integral parts of agricultural labor. Later, history saw a shift in attitudes toward lower-status humans and animals, followed by evolving perspectives on technology (in line with Simondon's observations).

Additionally, Bruno Latour's works, especially his actor-network theory, encourages a rethinking of the role of technology and objects in human society. Latour argued that technologies could not simply be instruments controlled by humans; they are equal actors within a network of interaction [25]. This idea supports the concept of democratization in education, where technologies like Generative AI play an active role in creating knowledge and teaching.

Thus, democratization as the social culture of constructionist education in the twenty-first century reaches a qualitatively new level. Generative Socialization, in the case of constructionism, manifests in the development of intellectual democracy, where both students and technologies collaboratively create knowledge and content, weakening hierarchical relationships and giving way to more equitable forms of interactions. Education, in turn, ceases to be strictly hierarchical, and technologies become active participants in learning and knowledge formation.

4.2 Spiritual Culture of Constructionism in the Generative AI Era

Today, in retrospect, it seems that spiritual culture was the most prominent component of the culture of constructionism. A notable example of this is the concept of the 'object-to-think-with,' introduced by Papert in his influential book *Mindstorms.* At the beginning of the book, Papert recounts a personal childhood experience that shaped his thinking for years—his fascination with playing with gears. This enjoyable activity became a means for him to explore and understand the world, helping him grasp complex mechanical and mathematical concepts. The 'gears of my childhood' provided Papert with a personalized, intimate learning experience, perfectly suited to his unique way of interacting with the world [21].

The gears were Papert's 'objects-to-think-with' and while realizing that his own experience in which he "fell in love with gears", was an individual one, and could not be duplicated for others, he believed that personal computers that could "take on a thousand forms and can serve a thousand functions, it can appeal to a thousand tastes", would be able to become an 'object-to-think-with,' for all children [21].

As part of the efforts to transform the education system by utilizing computers as 'objects-to-think-with,' the Turtle was created—an interactive object that children could engage with through coding using LOGO, a programming language. When considering Papert's vision of the computer as an 'object-to-think-with,' like the gears were for him, there is one clear difference, that is moving astray from that vision—the need to apply coding and traditional algorithmic thinking as a mitigator between the child and the Turtle. This aspect of the learning experience does not align with the seamless, personal, and intimate interaction characteristic of working with gears. In fact, it seems that the constraints of technology, which require precise and non-negotiable programming, significantly limited the realization of this vision. It is important to emphasize that, despite this limitation, computers and early digital tools did enable children to experiment with ideas and engage in activities that fostered self-reflection and self-identity formation [18]. Programming these objects gave children a tangible, manipulable space to explore according to their personal styles and preferences, while becoming familiar with abstract concepts.

Today, with the advent of Generative AI, the concept of the 'object-to-think-with' has evolved dramatically, reaching its full potential and beyond. This evolution has significant implications for the formation of knowledge and the development of self-identity which lead to a broader educational and cultural landscape. Historically, today's interactions with Generative AI systems transcend the limitations of traditional coding, enabling a seamless, intimate two-sided dialogue. Historically, computers provided feedback based on predefined rules, adhering to the user's commands. In contrast, interactions with Generative AI models are characterized by a symmetrical co-creation process, where responses generate content and appear to form knowledge alongside the human user. This interaction fosters the creation of new ideas and provides reflective feedback on one's thought process, allowing children to become true *Bricoleurs*, forming new knowledge in a personalized, co-creative process akin to playing with data on an artist's endless canvas.

Another important aspect is Generative AI's ability to generate empathetic responses that consider human feelings—a layer that was not present in the traditional 'object-to-think-with' relations (at least not reciprocally). This capability enhances the development of self-identity, making it a deeper, more immersive process, reflective of one's emotions and feelings. In this sense, Generative AI as an 'object-to-think-with' has a more comprehensive impact on 'shaping' one's identity and its evolution.

Generative AI brings about a full realization of Papert's 'object-to-think-with,' allowing a both rich and intimate Bricolage like co-creation dialogue, between teachers, learners, and computers, in their formation of knowledge and the development of self-identity. In fact, it may be said to surpass Papert's vision, which described an 'object-to-think-through' rather than an 'object-to-think-with' in its full extent. Papert envisioned intimate, one-sided relations that enabled personalized mind manipulations and abstract learning but did not include the emotional, interpersonal aspects implied by the term 'with.' Today's Generative AI, therefore, functions more as a 'partner-to-think-with' rather than merely an object turning spiritual culture into the culture of Existential Self-Awareness.

4.3 Technological Culture of Constructionism in the Generative AI Era

In Papert's time, the technological culture of constructionism was built based on computational thinking. The central idea was to use programming as a means of expressing and creating knowledge. This was the basis of the technological culture of constructionism, where students, working with computers, created their own worlds by programming them. Programming developed students' skills in structural and algorithmic thinking, which contributed to their educational growth.

However, in the era of Generative AI, this is changing. Programming no longer plays the key role it once did. Interaction with AI now occurs through natural language, making access to technology much easier. Instead of coding, students can formulate problems, and the AI will generate solutions based on the context. This opens new learning opportunities where students can focus on concepts and ideas without getting bogged down in the technical details of implementation.

This shift marks the emergence of a new technological culture of education. In contrast to the traditional approach that views technology as merely an instrument here AI becomes an active partner in the educational process, transforming the way knowledge is understood and interacted with. The technological culture of the Generative AI era no longer demands deep programming knowledge but rather a new type of thinking focused on problem-solving and understanding how AI functions. This shift in focus from technical implementation to understanding and interacting with AI reflects a profound change in the way technology influences the learning process.

The shift from programming to interacting with AI through natural language marks the emergence of a new technological culture in education, which we call Epistemological Technological Culture. Here, the emphasis is less on the technical implementation of tasks and more on cognition, understanding, and problem-setting, where AI acts as a full partner rather than a tool. This shift reflects profound changes in educational processes and in the way, students interact with technology.

The new technological culture requires a new type of thinking, where the student should learn to effectively interact with AI, understand its capabilities and limitations, but without having to write code. This opens access to knowledge to a wider audience, democratizing the learning process, but also raises questions about how critical thinking and creative problem-solving skills will develop.

Thus, the technological culture of constructionism in the era of Generative AI differs fundamentally from that of Papert's time. This shift underscores the need for a new epistemological paradigm, in which technologies are not merely tools but become active participants in the process of interaction.

5 Conclusions

This study explored the transformative implications of Generative AI on the educational system from a comprehensive cultural perspective. By employing a three-dimensional cultural model, we analyzed the evolution of education and the changes necessary to adapt to this new technological paradigm. The results of our study can be summarized as follows.

The social culture of education in the era of Generative AI involves adapting and rethinking collective norms and interactions between humans and emergent chatbots, that can be considered as full-fledged partners of humans. AI transforms the ways of social interaction and communication, fostering new forms of engagement between students, educators, and technologies. This influence leads to the formation of new social norms, where collective experiences are enriched through collaboration with AI, and traditional forms of social integration are adapted to new digital and virtual spaces. We defined the social culture of the Generative AI as Generative Socialization.

The spiritual culture of education in the era of Generative AI involves a deepened self-awareness, where Generative AI serves as a catalyst for rethinking personal values, beliefs, and meanings. Generative AI fosters the development of a new level of existential self-awareness, enabling students to interact with AI to explore and shape their own identity, transcending traditional education. We defined the spiritual culture of the Generative AI era as the culture of Existential Self-Awareness.

The technological culture of education in the era of Generative AI is a culture in which technologies cease to be mere tools and become active participants in the educational process. This marks a shift from viewing technologies as a 'black box,' requiring students and educators to develop a deeper understanding of how they work. Generative AI contributes to an epistemological shift, turning technologies into a means of knowledge that not only supports but also shapes new ways of thinking and learning. We defined the technological culture of the Generative AI era as Epistemological Technological Culture.

We also studied the culture of constructionist education, emphasizing its innovative tendencies, which demonstrate the potential of Generative AI in learning.

The research has both theoretical and practical significance. The model we propose reflects how education functions as a cultural technology in the Generative AI era. The model helps to understand the directions of forthcoming educational transformations and offers a framework that can be applied in further research of these changes. Our findings demonstrate the need to modify educational strategies and structures so that they would be able to address the challenges and make full use of the opportunities Generative AI offers.

Future Work. Through a culturological lens, this paper's analysis of how generative AI is transforming education provides a foundation for future research into the intersection of artificial intelligence and pedagogical practices. Several promising research directions emerge: exploring personalized learning and collaborative creativity across diverse educational settings, developing ethical frameworks that address bias and privacy concerns, studying the socio-emotional impact of human-AI interactions, and examining AI's potential roles as co-teacher and co-learner. Additionally, researchers should investigate how constructionist learning approaches can be adapted for an AI-enhanced educational landscape. This theoretical and empirical research agenda based on the proposed cultural studies aims to advance our understanding of effective AI integration in education while preserving essential human elements of teaching and learning.

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Application of Digital Method for Processing Distributed Digital Linguistic Resources

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Abstract. This article addresses the challenge of effectively processing and utilizing distributed digital linguistic resources to enhance the teaching of philological disciplines. Current efforts emphasize the application of digital methods, including statistical, corpus-based, and lexicographic techniques, integrated with artificial intelligence (AI) tools, such as machine learning and neural networks. The proposed solution centers on the development of a virtual lexicographic laboratory, the "Multimedia Dictionary of Infomedia Literacy," which offers an innovative digital approach to language education, linguistic research, and telecommunication applications. The primary idea is to employ these digital and AI-driven methods to analyze and organize vast amounts of linguistic data, making them accessible and useful for educational purposes. This approach has been tested in educational environments, demonstrating effectiveness in advancing academic resilience, particularly among doctoral students engaged in philological research. Key results indicate that the digital methods facilitate deeper engagement with language content, offering tools that adapt to individual learning needs and enhance the processing of large datasets. Case studies, including the Science4Brave Cluster, highlight the role of these tools in fostering critical thinking and academic resilience in times of crisis. Significantly, the laboratory's tools have shown value in telecommunication by supporting the transmission and analysis of linguistic information, adapting content for efficient communication across digital platforms. This work underscores the potential of digital and AI-enhanced methods in processing linguistic resources, advancing language learning, and contributing to the broader discourse on the role of technology in modern linguistics.

Keywords: Digital Linguistics Methods · Processing Large Distributed Digital Resources · Virtual Lexicographic Laboratory · Multimedia Dictionaries · Infomedia Literacy · Artificial Intelligence · Doctoral Studies

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1 Introduction

In the digitized society of the 21st century, knowledge is becoming one of the most important factors in every state's cultural, economic, technological, and humanitarian development. Knowledgeable information can be stored, transferred, and processed in various forms, including symbolic forms. The same information can also have different forms of expression, carried out through certain sign systems. Such symbolic systems are constructed from basic elements ("alphabets") that are "equipped" with relevant rules for performing operations. To ensure the information process, at least three components are necessary: the source of information, its receiver (recipient), and a communication device that ensures the delivery of information from the source to the recipient. Thus, information is always information about a certain object, which is its source.

The main portion of new knowledge is obtained directly from texts created in natural language (languages) and acting as carriers of linguistic information. The dynamic development of information and communication technologies circumstances the transformation of natural language into the language of symbols, with the help of which large arrays of linguistic information are codified and stored. For example, a digital device stores and processes information using the binary system.

The new data's high-speed appearance and the growth of stored information stimulate the need for highly effective information digital technologies and intelligent systems, along with the search for new ways of information automatic processing, its systematization, appropriate classification, and presentation at the request of the user.

In particular, the transition to digital information, and the transformation of various content into a suitable digital resource is the typical function of digital technologies, specifically for conducting linguistic research. Figure 1 shows the process of converting linguistic information into digital content. At the initial stage, the technological process of processing language units (pictures, emoticons, texts on various media, graphics, etc.) is highlighted, which is characterized by the selection of the necessary means of digitalization and the creation of digital content with the possibility of further statistical and mathematical modeling and analysis of linguistic content.

In modern linguistic research [10, 12, 14] the digital (automatic) method of processing linguistic information is preferred.

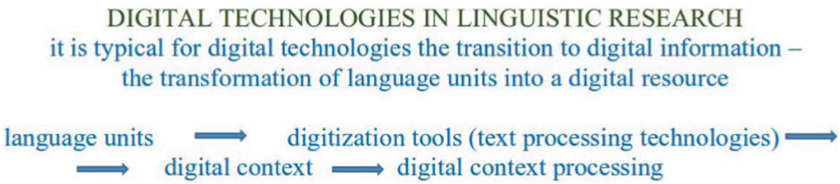

Fig. 1. Digital technologies in linguistic research.

The specified method provides the possibility of processing large arrays of data, the ability to work with any content (paper and digital media, etc.), as well as the further digital processing possibility: quantitative and statistical calculations, modeling, providing access to a wide range of users; the possibility of transformation into other environments, and thus ensures the openness of Ukrainian science in the European and world philological space [10, 14].

To the main trends of the network world, which determine the development of digital technologies in linguistic research, scholars add such trends as virtualization of the language environment, intellectualization, and work with Big Data.

According to the main trends, there is a need to search for new effective methods of studying linguistic information, creating software tools, and their further effective application for teaching philological disciplines in higher education.

To ensure the availability of software products to students—future philology teachers, as well as to a wide range of interested users, it is important to cooperate with researchers who create linguistic software tools, carry out digitalization of content, automatic processing, systematization, classification of large data sets, with teachers of philological disciplines of higher education institutions. In 2018–2022, by the agreement, such research cooperation is carried out between the Ukrainian Lingua-Information Foundation of the National Academy of Sciences of Ukraine (hereinafter—ULIF NAS of Ukraine) and the Department of Ukrainian Language and Literature of Sumy State Pedagogical University named after A. S. Makarenko (hereinafter—SumDPU).

Over the past years, researchers of the ULIF of the National Academy of Sciences of Ukraine have created the Ukrainian National Linguistic Corpus (Ukrainian National Linguistic Corpus) [16], the Integrated Lexicographic System "Dictionaries of Ukraine online" (Integrated Lexicographic System "Dictionaries of Ukraine online") [7], a bank of oceanographic data based on ontological interactive documents [12, 15].

According to the analysis, the paradigmatic foundations of linguistics of the first half of the 21st century, which already "qualifies as evolutionary-informational-phenomenological" [14] are being researched, as well as ontologically driven lexicographic systems are developing [12].

The technical features of the virtual laboratory "Multimedia Dictionary of Infomedia Literacy" have been outlined in cooperation with the ULIF of the National Academy of Sciences of Ukraine and the "MEDIA & Teacher's CAMPUS" educational and research center of the Department of Ukrainian Language and Literature of the A. S. Makarenko State Pedagogical University (Ukraine) [8], a review of the creation and use of the "MEDIA&CAPSULES" transdisciplinary cluster as a means of raising the level of media culture was carried out.

The analysis confirms the lack of systematic research on the use of digital methods in teaching, which has actualized the need to characterize the use of digital methods in teaching philological disciplines.

The object of research: Distributed digital linguistic resources, specifically focusing on their application in teaching philological disciplines and doctoral studies. This includes resources like the virtual lexicographic laboratory "Multimedia Dictionary of Infomedia Literacy" and platforms such as the Science4Brave Cluster.

The subject of research: The digital methods and techniques for processing these distributed linguistic resources, including lexicographic research, statistical and corpus-based methods, as well as artificial intelligence approaches (machine learning, deep learning, neural networks) and their use in language learning, teaching, and research.

The article aims to characterize the application of the digital method in the philological disciplines teaching, the task is to outline the methods of researching digital linguistic information, in particular the methods of statistical linguistics, corpus technologies, artificial intelligence, lexicographic method, we will find out the specifics of using the virtual lexicographic laboratory "Multimedia Dictionary of Infomedia Literacy" in teaching philological disciplines and advancing doctoral studies.

Scientific novelty. The work results made it possible to establish the main methods of digital linguistic research, which may be used to study linguistic material in higher education, doctoral education particularly. In the group of presented methods, the main ones are highlighted: statistical, corpus, and lexicographic research method based on the theory of lexicographic systems, and the method of artificial intelligence: machine learning, deep learning, and neural networks.

Methods and techniques. In the study, we considered the thesis that the method forms approaches to the language and speech phenomena analysis. Terminological and conceptual analysis was used to solve the set tasks, and in particular to clarify the essential characteristics of digital linguistic information research methods.

The characteristics of such methods as descriptive, statistical (mathematical), corpus technology method, lexicographic, and artificial intelligence methods (machine learning, "deep" learning, neural networks) are presented within the scope of the actual research.

Following the tasks, we will outline the research methods of digital linguistic information. Researchers characterize linguistic methodology as an independent branch of theoretical knowledge, which is projected into a general methodology—the study of ways of knowing and understanding reality and the formation of the internal reflective experience of a person, as well as research guidelines, principles, and procedures for analyzing objects in the linguistic environment.

The ULIF of the NAS of Ukraine has developed the theoretical scientific and technical foundations of research methods for digital linguistic information.

Among the main methods of digital linguistic information research, which serve as the basis of modern linguistic research, we highlight the statistical method of information processing (the method of statistical linguistics), the method of corpus technologies, lexicography, and artificial intelligence. The classification of research methods is formed according to the purpose of their use and must take into account the specifics of the research source base. The proposed research methods do not contradict classical research methods and can be used in combination.

L-systems (see (1)) serve as the framework for organizing linguistic constructs

$$\Sigma = \{\Sigma_{cm}, \Sigma_{exm}, \Sigma_{inm}, \Phi, \Psi, \Xi\} \tag{1}$$

where Σ_{cm}, Σ_{exm}, Σ_{inm} represent conceptual, external, and internal models, respectively. These systems facilitate the transformation of linguistic information into structured formats for digital processing, ensuring consistency across user interactions. By defining mappings ($\Phi : \Sigma_{cm} \rightarrow \Sigma_{exm}$, $\Psi : \Sigma_{cm} \rightarrow \Sigma_{inm}$), linguistic resources can be dynamically adapted for research and teaching.

The statistical method, in particular, considers language as a system-structural entity that has separate subsystems—levels represented by the corresponding units: phonemes, morphemes, lexemes, and syntagms. Thus, the language is characterized not only by qualitative but also by quantitative indicators. Quantitative methodology has become more effective with the advent of appropriate open-access software.

Figure 2 presents an example of the application of the statistical method in linguistic research, in particular, to identify features of functional language styles and features of the style of individual authors, chronological features of language units, etc.

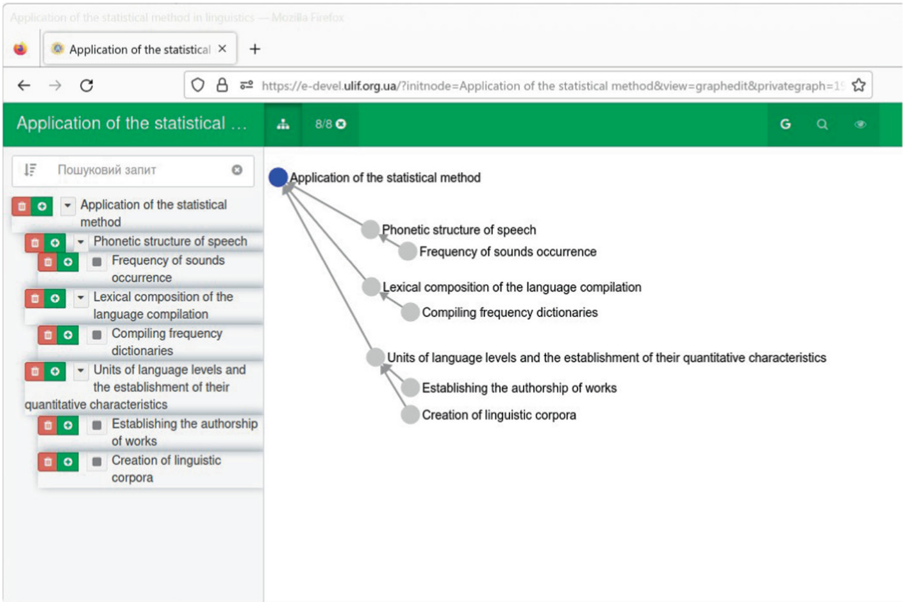

Fig. 2. Illustration of the statistical method application in linguistic studies.

2 The Integrated Lexicographic System "Dictionaries of Ukraine Online"

Methods of statistical linguistics are used for linguistic monitoring of language functioning in a specific type of discourse (political, scientific, mass media, etc.), and for content analysis (detection of the state of public consciousness). The subject of monitoring can be types of language errors, the sphere of foreign language borrowings, new words, and meanings, new metaphors, thematic distribution of vocabulary (for example, the vocabulary of temporal and spatial relations, vocabulary for marking feelings and emotions, etc.), features of the use of certain grammatical forms in texts or syntactic constructions.

An example of the identification and comparison of synonymous series in the lexemes of *благодать (розм.), благо (заст.)*, and the modern polysemous equivalent добро in the Integrated Lexicographic System "Dictionaries of Ukraine online" is presented in Fig. 3.

Fig. 3. Example of detection and comparison of synonymous series in lexemes: благодать (розм.), благо (заст.), добро (Integrated Lexicographic System "Dictionaries of Ukraine online").

Modern linguistics offers several methods and strategies of the lexical system units' analysis, due to certain aspects of research. We consider using the case technology method expedient as a necessary component for creating open-type minicases.

We interpret neural networks as a subset of artificial intelligence, which focuses mainly on designing systems that allow learning and making predictions based on certain experiences. Artificial intelligence is considered as a form of systems individualization, which is characterized by linguistic status [10]. It is about the imitation or replication of human cognitive traits by machines, such as computer programs.

In lexicographic systems, these networks aim to replicate cognitive processes by structuring and analyzing linguistic data dynamically. The operation of a neural network layer can be expressed as:

$$a^{[l]} = g\left(W^{[l]}a^{[l-1]} + b^{[l]}\right), \tag{2}$$

where $a^{[l]}$ represents the activation at layer l, $W^{[l]}$ and $b^{[l]}$ are the weights and biases for the layer, and g is an activation function such as ReLU or sigmoid. This mathematical process mimics how neurons in the brain generate recognition features with increasing abstraction across layers.

The general concept of "artificial intelligence" covers several areas: expert systems, systems for characteristic analysis and robotics; and the ability of the engineering system to process, apply and improve the acquired knowledge. It is a system that has certain signs of intelligence, that is, it can recognize and understand; find a way to achieve results, and make decisions.

A critical advancement in the application of digital methods for processing distributed digital linguistic resources is the development of intelligent lexico-conceptographic systems. These systems harness machine learning, particularly neural networks, to process and conceptualize linguistic data dynamically.

Modern neural networks differ significantly from biological neural networks, which leads to several well-known problems in artificial neural networks:

- Challenges in creating efficient learning algorithms.
- Overfitting (the tendency of a model to perform well on training data but poorly on unseen data).
- Uncontrolled focus on local features.
- Memory stability-plasticity dilemma.
- Classification and identification problems during recognition.
- Network dimensionality and memory capacity challenges.
- Difficulties in implementing associative recognition.

Currently, these issues manifest in the fact that most neural networks in practical use typically have multi-layered and often non-homogeneous architectures. For instance, deep neural networks (DNNs) may contain dozens or even hundreds of layers. Neurons in each internal layer process information, generating recognition features with increasing levels of generality. Usually, the structure of inter-neuron connections between layers is uniform across different layer types.

While artificial neural networks still fall short of accurately modeling biological brain processes, certain areas, such as the visual system, have been modeled more effectively. In this system, only two main stages of processing are needed for recognizing isolated visual images (e.g., faces, animals, geometric shapes). First, primary features are extracted in the primary visual cortex, followed by complex whole-image formation in the secondary visual cortex.

In most artificial neural networks, the process of perception and transmission of information across layers is parallel over the entire receptor field. However, in the brain, perception and subsequent processing occur selectively, driven by the attention system. This selective process involves concept formation during learning, which becomes part of the neuron's memory. A concept sets the necessary and sufficient conditions for neuron activation, which in turn defines the recognition features for classification and identification. In this way, concepts serve as filters for incoming information, tuned to specific recognition features learned during training.

The learning process of a neuron involves two stages: (1) concept formation (definition) and (2) concept minimization, which refers to finding the minimal vector of input signals. A minimized concept is an invariant, non-modifiable unit during further learning. Such a concept determines the recognition class and acts as an information model of the neuron's dendritic tree.

What sets this technology apart from traditional machine learning approaches is its integration of linguistic-mental processes and emotional intelligence in building dynamic networks of concepts. Conceptualization in this context is not merely a technical process but a cognitive act shaped by both individual and societal consciousness, which can be effectively modeled and described through natural language.

A critical advancement in the application of neural networks is the integration of concept minimization, which aims to simplify input representations. Concept minimization is achieved by finding the smallest invariant vector that retains essential meaning during training:

$$C_m = \text{argmin}\left(\|x - \hat{x}\|\right) \tag{3}$$

where x is the input signal, and $\hat{x}$ is the approximation after training. This process filters incoming linguistic data, reducing dimensionality while maintaining critical features for classification and interpretation.

Internal conceptualization occurs within the structure known as the Main Cognitive Tract [10], which follows the sequence:

$$P \to A \to E \to A \to U \to R \to A \tag{4}$$

representing perception (P), acceptance (A), experience (E), awareness (A), understanding (U), reflection (R), and action (A). This cognitive sequence forms the foundation of conceptographic graphs in lexicographic systems, where concepts are progressively refined into actionable insights.

In practice, this cognitive process is built in the form of lexicographic descriptions (meanings), conceptographic descriptions (senses), and semantic determinants, conceptual fields, and conceptual states, which form pathways in a conceptographic graph.

As a result, we develop dynamic ontologies based on the theory of lexico-conceptographic systems, also known as mental ontologies. This enables the development of artificial intelligence in ways not achievable by current machine learning algorithms, particularly in the areas of predictability, consciousness modeling, and the use of world models for self-learning and self-improvement.

Dynamic ontologies are key to the functionality of intelligent lexico-conceptographic systems. In simple terms, ontologies represent structured knowledge about a particular domain. In the case of language and linguistic resources, ontologies allow for the formalization of relationships between words, concepts, and their meanings. However, dynamic ontologies go a step further: they are adaptable, continuously evolving as new data is ingested and processed.

Dynamic ontologies are developed to organize and adapt knowledge structures efficiently. Ontologies are defined as:

$$O = \{X, R, F\} \tag{5}$$

where X denotes elementary information units (e.g., lexemes), R represents relationships (e.g., synonyms, antonyms), and F includes functions for processing and retrieving data. These ontologies support the continuous evolution of lexicographic systems, ensuring adaptability to new linguistic data.

A central innovation in this field is knowledge compression, where neural networks and ontologies collaboratively reduce the complexity of linguistic representations. The process identifies the minimal knowledge structures necessary for accurate data modeling:

$$K_C = \arg \min_{K' \subseteq K} \left(\sum\nolimits_{k_i \in K'} \text{Uncertainty}(k_i) + \lambda \cdot \left| K' \right| \right) \tag{6}$$

where λ balances between reducing uncertainty and limiting the size of K'. Uncertainty for each element is quantified using entropy:

$$\text{Uncertainty}(k_i) = -\sum_j P(k_{ij})\log P(k_{ij}) \tag{7}$$

or variance-based measures:

$$\text{Uncertainty}(k_i) = \sigma^2(k_i) = \frac{1}{N}\sum_{j=1}^{N} \left(k_{ij} - k_i^-\right)^2 \tag{8}$$

where k_i^- is the mean value of k_i over N observations. Neural network-generated confidence scores further guide this process:

$$\text{Uncertainty}(k_i) = 1 - C(k_i) \tag{9}$$

where $C(k_i)$ is the confidence level of k_i being accurate or relevant.

The hybrid architecture of our AI platform supports the creation of multi-layered linguistic corpora that facilitate decision-making processes. It includes a set of cognitive services capable of automatically generating ontologies for both individual documents and large document groups. During ontology generation, the AI platform identifies attribute data that qualitatively and quantitatively characterizes the document contents.

To ensure high levels of semantic representativity, neural networks are generated based on the thematic content of the documents. All processes within these neural networks can be structurally represented by the ontologies created during semantic and cognitive document analysis. These networks identify deep inter-contextual relationships between documents, even when separated by different semantic distances, establishing hierarchies among document objects.

Based on these hierarchies, decision-making services are provided, which detect critical criteria in the analyzed information. These services enable decision-makers (DM) to formulate and solve decision-making tasks. The system's information environment is formed based on an ontological description of the domain, allowing DMs to automatically retrieve a list of indicators characterizing the chosen alternatives.

During the decision-making process, DMs solve tasks such as:

- Ranking alternatives: Ordering a set of alternatives for impact assessment and selecting the optimal solution.
- Rating alternatives: Calculating ranking scores based on a user-selected preference system.
- Rational choice: Identifying the best or worst alternative based on selected criteria.
- Multi-criteria comparative analysis: Visualizing solutions for various subsets of criteria, depending on the DM's preferences.

In the AI platform, we employ transformer generative networks for automatic structure generation over texts (or contexts). Their operation is expressed as:

$$\text{Output} = \text{Softmax}(W_o(W_h X + b_h) + b_o) \tag{10}$$

where W_h and W_o are weight matrices for the hidden and output layers, b_h and b_o are biases, and X is the input. The softmax function ensures the output probabilities sum to one, enabling efficient decision-making and data representation.

The generated structure corresponds to the Subject's perspective, expanding and supplementing it. This set of perspectives is presented as basic ontologies.

A basic ontology is a linguistic ontology created using lexicographic technologies. Key systemic properties of lexicographic systems include hyperchains, hypercycles, completeness, and non-contradiction. The primary sources for basic ontologies are explanatory dictionaries and terminological dictionaries.

Utilizing the general principles of dictionary construction (and corresponding ontologies), dynamic ontologies can be automatically generated from any text, creating a dynamic picture of the domain critical for decision-making in different areas.

The dynamic compression of knowledge technology allows the extraction of concept structures from any text, comparing them with concepts from basic and dynamically expandable ontologies, much like how a person uses a dictionary. Existing static knowledge will be compressed as much as possible, with uncertainties being interpreted based on the required level of detail.

The dynamic ontologies and knowledge compression are key characteristics of our hybrid lexicographic approach to artificial intelligence.

Finally, neural networks employ hierarchical mappings within lexicographic systems to classify lexemes ($\gamma : L_T \to S$), identify terms ($\phi : D_T \to S$), and extract relations ($\sigma : T \to R$). This comprehensive integration enables the synchronous processing of large linguistic datasets, fostering innovative applications in multimedia dictionaries and philological research tools.

In the formula for knowledge compression:

$$K_C = \arg\min_{K' \subseteq K}\left(\sum\nolimits_{(k_i \in K')} \text{Uncertainty}(k_i) + \lambda \cdot \left|K'\right|\right) \tag{11}$$

where:

- K: The complete set of knowledge elements available in the system. Each element k_i within K represents a distinct piece of information, such as a lexeme, concept, or relationship.
- K' : A candidate subset of K, meaning $K' \subseteq K$. It includes only those elements that are deemed critical or most relevant after applying the knowledge compression algorithm.
- $\left|K'\right|$: The size of the subset K', which is penalized in the objective function to encourage a compact representation of knowledge.

Purpose of K': The optimization process selects K' such that it:

- Minimizes the total uncertainty:

$$\sum\nolimits_{k_i \in K'} \text{Uncertainty}(k_i) \tag{12}$$

- Controls the subset size $\left|K'\right|$, with a penalty term $\lambda \cdot \left|K'\right|$ to prevent excessive retention of unnecessary elements.

K' is the output of the compression process, representing the compressed knowledge base. It contains only the most essential elements needed for accurate linguistic analysis, ensuring efficient storage and retrieval while reducing computational overhead.

A significant challenge in modern machine learning (ML) and large language models (LLMs) is efficiency. While some LLMs achieve relatively high performance of text analisis and generation (over 80 acc. in average of various test metrics [13]) but with relatively slow generation speed (from tens to several hundreds of tokens per second) and some other techniques with high speed but relatively low performance (under 45 acc. in average). In text embedding tasks [11] (clustering, classification, retrieval etc.—MTE) even popular models with high speed and relatively high performance (over 65 acc. in average) like all-mpnet-base-v2 and all-MiniLM-L12-v2 have poor results in many cases (like special subject area retrieval etc.).

To address this, we propose a hybrid approach: utilizing conceptographic analysis, basic ontology technology, and dynamic knowledge compression. This approach significantly improves accuracy while maintaining high processing speeds (ranging from tens to thousands of tokens per second).

In the context of distributed linguistic resources, such as those used in the Virtual Lexicographic Laboratory "Multimedia Dictionary of Infomedia Literacy", intelligent lexico-conceptographic systems allow for automated and scalable processing of vast amounts of linguistic data. These systems address many of the known challenges faced by neural networks, such as overfitting, the problem of classification and identification, and limitations in memory capacity. By applying these systems to teaching philological disciplines and doctoral studies, educators and researchers can leverage the power of deep neural networks (DNNs) to create more nuanced, flexible, and context-aware educational tools.

For instance, in the Virtual Lexicographic Laboratory, DNNs can process large textual corpora by recognizing patterns and generating higher-order concepts based on linguistic data. This aligns with the conceptualization process within neural network-based learning, where concepts serve as the building blocks for classifying and interpreting linguistic material. These networks, often multi-layered with intricate connections between neurons, can process data in ways that mirror human cognitive structures, enabling the development of advanced educational resources such as multimedia dictionaries.

In educational settings, this has been particularly impactful. By minimizing and refining concepts through neural learning, virtual lexicographic systems enhance the efficiency of language learning tools, allowing for a more personalized and adaptive learning experience. Concepts, once identified and minimized, act as filters for incoming linguistic data, making it easier to manage and process vast arrays of distributed digital linguistic resources in real-time. This is especially important in the context of teaching philological disciplines, where students interact with complex linguistic data through dynamic ontologies.

Furthermore, the use of dynamic ontologies—structured representations of knowledge that evolve as new data is processed—facilitates the creation of multimedia dictionaries that are not static but adapt to changes in the linguistic environment. These dictionaries can handle tasks such as automatic generation of lexicographic entries, semantic analysis, and conceptual mapping, enabling more effective teaching and learning outcomes. For example, the Multimedia Dictionary of Infomedia Literacy uses these methods to provide students and researchers with a deeply interactive platform for exploring language concepts across various media and contexts.

This technology also improves academic resilience, particularly for doctoral students engaged in philological research. By integrating these AI-driven methods into the educational process, students can explore large datasets, generate semantic relationships, and conceptually model language systems that reflect both traditional linguistic structures and modern media environments.

Neural networks in this context address common challenges such as the need for efficient algorithm development, dimensionality issues, and the integration of associative recognition systems that enhance the processing of linguistic information in distributed environments. In the Virtual Lexicographic Laboratory, these advancements support the synchronous processing of large-scale linguistic data, enabling educators and researchers to offer cutting-edge linguistic resources to a wide audience, including those engaged in doctoral studies.

Through these tools, teaching philological disciplines becomes more engaging and accessible, as students can directly interact with dynamic, evolving content that responds to their needs. The use of artificial intelligence in this context fosters critical thinking and enhances the understanding of complex linguistic structures, ultimately bridging the gap between traditional linguistic methods and modern digital research techniques.

In summary, the integration of intelligent lexico-conceptographic systems and neural networks into the processing of distributed digital linguistic resources provides significant benefits for the development of multimedia dictionaries and the Virtual Lexicographic Laboratory. These advancements offer innovative approaches to language teaching and research, contributing to the evolution of digital methods in philological education. By continuing to refine these systems, the potential for improved language learning outcomes, academic research, and doctoral studies is vast, as these tools provide both scalability and precision in the processing of linguistic data.

The practical application of the above-mentioned research methods proves the high efficiency of the implemented tools in the form of virtual lexicographic laboratories and grouped linguistic platforms, in particular multimedia dictionary products, which are actively introduced into the all-Ukrainian and European philological space.

The application of Big Data analysis methods and technologies and integrated platforms developed by the ULIF of the National Academy of Sciences of Ukraine (see Figs. 4 and 5) [8]: "Dictionaries of Ukraine online", "System of Linguistic Interaction "VLL", "Ukrainian Linguistic Corpus", etc.) is relevant.

In 2023–2024, specialists of the ULIF of the National Academy of Sciences of Ukraine, together with specialists of the Junior Academy of Sciences of Ukraine with the support of UNESCO, as well as the Ministry of Education and Science of Ukraine and the Ministry of Foreign Affairs of Ukraine, carried out scientific work on assessing the damage to the scientific infrastructure in Ukraine due to the war. As a result, a special lingua-informational analytical platform[1] was developed.

The results of this analysis [2] were presented at the Symposium "Rebuilding Scientific Ecosystem in Ukraine" in March 2024.

[1] https://polyhedron.ulif.org.ua/en/destroyed-property.

Academician of the National Academy of Sciences of Ukraine Stanislav Dovhyy took part in the work of the Symposium from the National Center «Junior Academy of Sciences of Ukraine», and from the National Academy of Sciences of Ukraine—senior researcher Maksym Nadutenko (as one of the platform developers) [2].

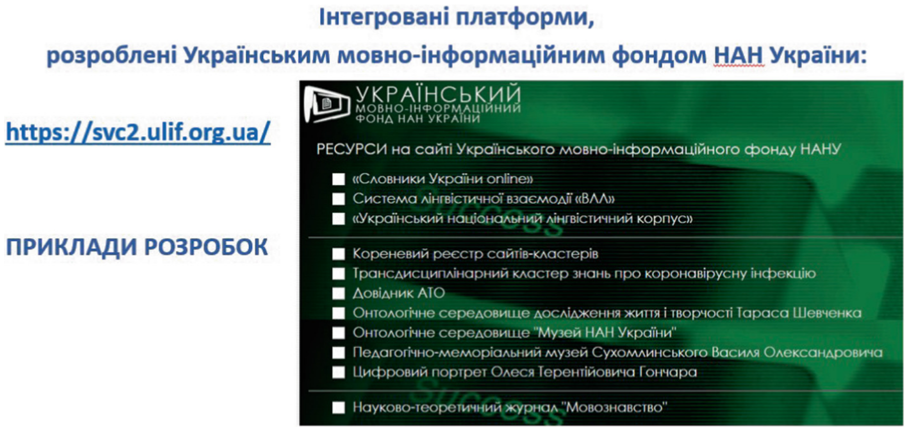

Fig. 4. Integrated platforms developed by ULIF of the National Academy of Sciences of Ukraine.

Assessments of damage to the scientific infrastructure in Ukraine due to the war were discussed and a comprehensive recovery plan was outlined [2]. The plan will serve as a road map for future actions and will be shared with relevant stakeholders to mobilize support and resources for its implementation.[2]

For modern studies of the language lexical system, it is advisable to use the lexicographic method. The method is primarily aimed at sequential selection and selective study of individual elements and their relations in the language system.

Currently, an active search for new techniques that use the lexicographic method of research in combination with automatic lexicographic systems is underway. We will give examples of lexicographic methods: vocabulary classification to create multimedia dictionaries of new types; open free associative experiment using automatic lexicographic systems; distributional analysis of semantems to determine the difference in the semes of a separate lexeme in a chronological section; analysis of juxtapositions and comparisons on the border of several languages, which is carried out for research to establish the frequency characteristics of the corresponding lexemes.

Among the software developments of the Ukrainian Lingua-Information Foundation of the National Academy of Sciences of Ukraine, which are used in the philological disciplines teaching in higher education institutions, are the following ones:

1. Video dictionary as a new method of onym material presentation.
2. Virtual onomastics laboratories as a tool for active interaction of specialists in remote mode.
3. Databases for anonymous information processing and large-scale analysis.

[2] https://www.unesco.org/en/articles/unesco-outlines-recovery-plan-ukrainian-science.

4. Linguistic corpora from onomastics using the developed linguistic marking.
5. Onotological excursions through the 3D panorama of the virtual onomastic museum as a new method of presenting onymic material.
6. The “POLYHEDRON”[3] system as a network tool to ensure interaction with information resources.

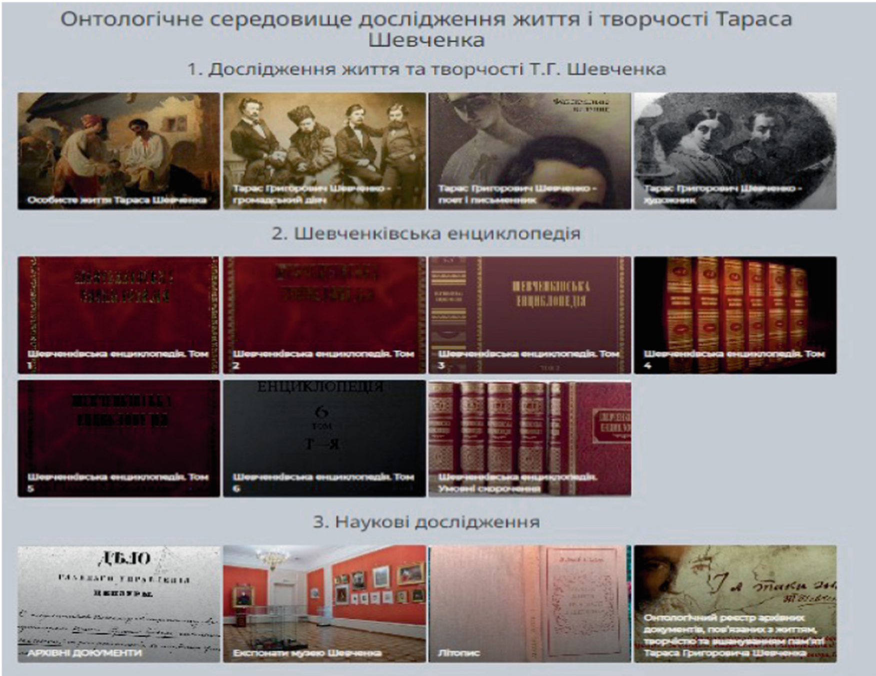

Fig. 5. Ontological environment for the study of the life and work of Taras Shevchenko.[4]

3 Virtual Lexicographic Laboratory “Multimedia Dictionary of Infomedia Literacy”

Below the specifics of using the digital method in teaching philological disciplines are provided based on the virtual lexicographic laboratory “Multimedia Dictionary of Infomedia Literacy” as an example, which was created for educational needs by partners—ULIF of the National Academy of Sciences of Ukraine and the educational and research center “MEDIA & TEACHER Campus” of the Department of Ukrainian Language and Literature of the Ukrainian State Pedagogical University named after A S. Makarenko.

[3] https://polyhedron.ulif.org.ua.
[4] https://shevchenko.ulif.org.ua.

The virtual lexicographic laboratory leverages ontology-driven L-systems ($O = \{X, R, F\}$) to create interactive linguistic environments, where X represents elementary information units (EIUs), R denotes relationships, and F includes functions for data manipulation. The system's architecture (according to Formulae 1)

$$\Sigma_O = \{\Sigma_{cmO}, \Sigma_{exmO}, \Sigma_{inmO}, \phi, \xi\} \tag{13}$$

extends standard L-systems to support ontology-driven interactive documents. This approach allows mapping ($\phi : \Sigma_{cmO} \to \Sigma_{exmO}$) and efficient organization of linguistic data for analysis.

Virtual lexicographic laboratory "Multimedia Dictionary of Infomedia Literacy" has been tested in the educational and research activities of future philology teachers of Sumy State Pedagogical University named after A. S. Makarenko, in particular in the student scientific circle on academic culture. The peculiarity of the virtual lexicographic laboratory is that it is an open multimedia environment designed for the interaction of participants in the educational process with digital media resources.

The software product comprehensively presents the toolkit, methodology, methods, and aspectology of scientific approaches important for media linguistics. The dictionary is built according to the classical alphabetic principle (see Fig. 6).

Multimedia dictionaries use lexicographic systems that define relationships and hierarchies of terms via ontologies ($O = \{X, R, F\}$). These systems implement term identification ($\phi : D_T \to S$) and relation identification ($\sigma : T \to R$) to link lexemes with their contextual definitions and interrelations. By representing lexemes as ordered sets ($t = \{l_1, l_2, \ldots, l_n\}$), the dictionaries facilitate dynamic exploration of linguistic data across different media types.

The terms and scientific concepts of the virtual lexicographic laboratory are the main issues of media linguistics, its methods, types of analyzed texts, and structural and functional language units of these texts.

Dictionary articles contain tangents to actual linguistic concepts, without which it is impossible to analyze the specifics of language in the mass media, which is a syncretic sphere of modern humanitarianism (primarily journalism, some political science, etc.).

In particular, the lexeme "manipulation of mass consciousness" (Fig. 7) is characterized as the psychological programming of people's thoughts and aspirations, their moods, and mental state to ensure such behavior that is necessary for a group of few owners of mass media, who exercise such influence, pursuing their personal selfish goals.

The lexeme register is based on the concept of infomedia literacy developed by the IREX Council for International Scientific Research and Exchange. The authors of the concept believe that the components of info-media literacy are media literacy; critical thinking; social tolerance; resistance to influences and manipulations; fact-checking; information literacy; digital security; visual literacy; innovativeness, and creativity development.

The multimedia dictionary on infomedia literacy emphasizes an interdisciplinary approach to education by introducing the main terms from the academic disciplines "Media Linguistics", "Media Literacy in the Educational Process", and "Culture of the Ukrainian Language and Stylistics", etc. into the register. For example, the lexeme "Web cartography" is presented as a geographical term—a set of technologies related to the

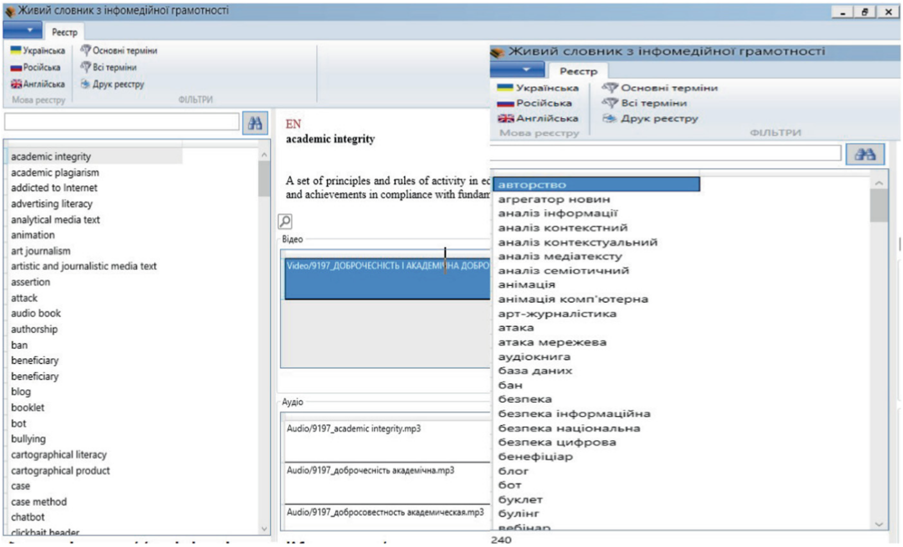

Fig. 6. "Multimedia Dictionary of Infomedia Literacy" dictionary structure.

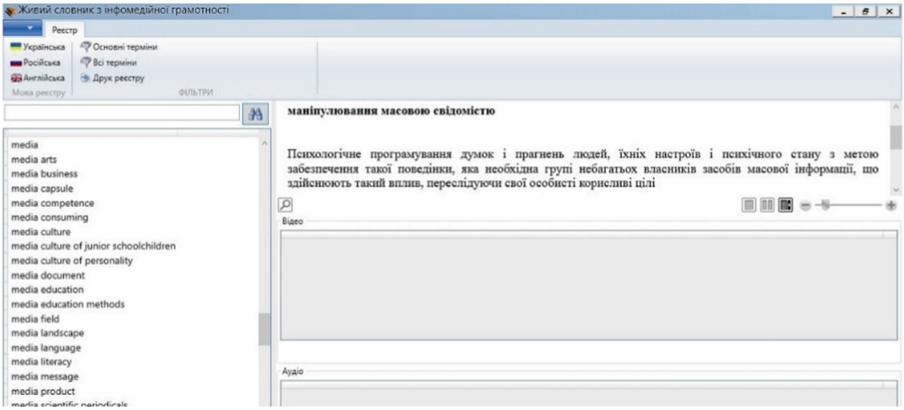

Fig. 7. Lexeme "Mass Consciousness Manipulation" in the "Multimedia Dictionary of Infomedia Literacy".

creation of various electronic maps, their placement, and processing in the web space (Fig. 8).

The multimedia dictionary is a unique digital product of virtual interaction between participants of the project (scientists, teachers of various disciplines, journalists, school teachers, and students) from different regions of Ukraine and abroad [10].

The dictionary was used especially intensively during the war to develop the vital skills of infomedia and digital literacy among student youth: the ability to rationally

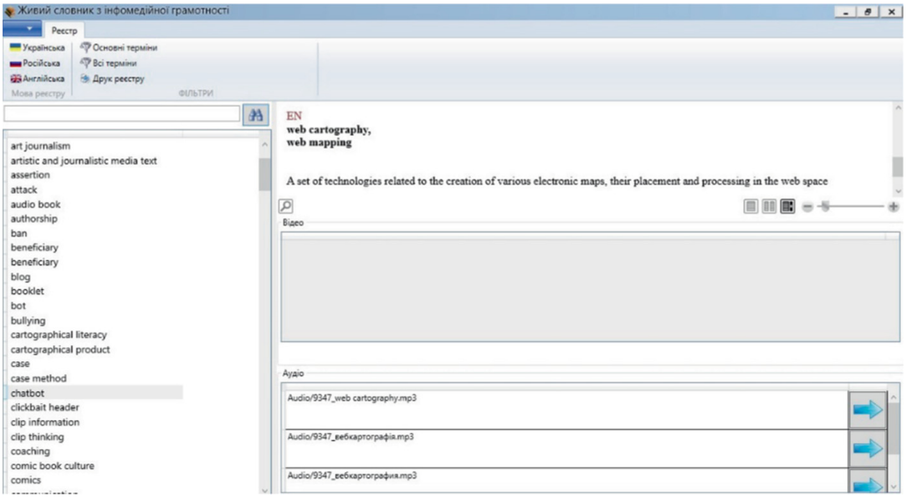

Fig. 8. The lexeme "Web cartography" in the Multimedia Dictionary of Infomedia Literacy.

consume media content, critically perceive information, distinguish facts from judgments, identify the emotional impact of the media, detect manipulative content, fakes, and master the techniques of communicative interaction.

The thematic modules and certain themes of the educational discipline "Ukrainian language culture and stylistics" were enriched with multimedia visualization of media terms *bullying, video blog, gadget, media safety, media literacy, media expression, online fraud, digital security, digital footprint, fact-checking, fake, troll, chatbot, etc.* Their definitions, translation, and interpretation in English and Ukrainian are offered, as well as a video clip according to the characteristics (Fig. 9).

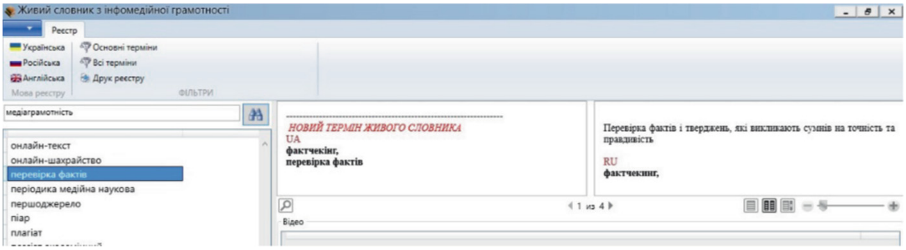

Fig. 9. The lexeme "fact-checking" in the "Multimedia Dictionary of Infomedia Literacy".

The use of a virtual laboratory gives the educational process greater interactivity: there is an opportunity to solve specific tasks with the help of various interactive methods (brainstorming, project work, situational tasks, etc.), and it increases the level of media culture, and critical thinking in war conditions. For this purpose, in cooperation with students of the specialty 014 Secondary Education. Ukrainian language and literature of A.S. Makarenko State University of Sumy, specialty 061 Journalism of the Mechanical

Engineering College of Sumy State University, Kyiv-Mohyla Academy, scientists of ULIF of the National Academy of Sciences of Ukraine created presentation videos. In particular, Fig. 10 shows the interpretation of the word gadget in presentation videos.

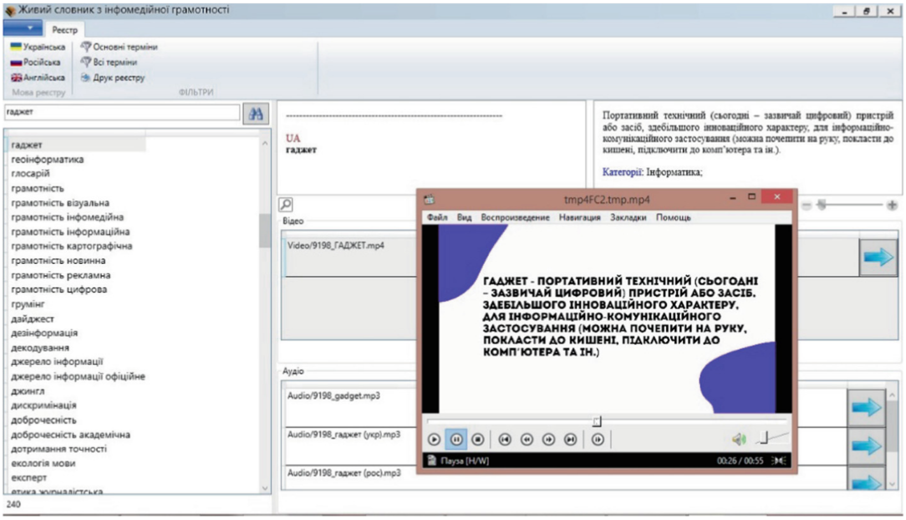

Fig. 10. Characteristics of the term gadget in the “Multimedia Dictionary of Infomedia Literacy”.

The authors of the video, Arina Stolbtsova, Myroslav Derevyanko, and Nataliia Ponomarenko, offer a short introduction—a skit-dialogue between students as an interactive format for presenting information. In classes, we analyze that the risk for such information is the dynamic nature of the language. If until recently the word gadget was not actively used in everyday speech, now due to its prevalence it is no longer a neologism, and the surprise of the heroes of the video about this word may seem strange. Therefore, further joint research on the use of the digital method in philological disciplines is needed.

The multimedia dictionary on infomedia literacy was included in the structure of the project “Learning the Ukrainian language in the New Ukrainian School” during the teaching of linguistic and methodical disciplines: students created short videos, visualizations on the language topic, compiled exercises for the school workbook “Ukrainian language. 5th grade, in particular, for the rubric “Speech workshop. Speak correctly!”.

The sustainability of the project of using the virtual lexicographic laboratory “in the teaching of philological disciplines consists in the expansion of the audience, the involvement of philological teachers and students of the National Academy of Statistics of Accounting and Auditing, and the use of the virtual laboratory as a simulator and the creation of new projects during educational and production practice: “Protected messengers”, “Financial security and fraud” (see Fig. 11).

Methodical materials for classes and research work in philology are compiled taking into account educational trends 4.0: digitalization of the educational environment, research, problem-oriented and project-based learning; we adhere to such principles

Fig. 11. Examples of students' works of the National Academy of Accounting and Audit Statistics for classes in linguistic disciplines.

as the principle of personal development, interactivity, visualization, interdisciplinary integration, soft integration of infomedia literacy, the aesthetic value of media texts, development of critical thinking.

4 Transdisciplinary Knowledge Cluster for Researchers at Risk "Science4Brave Cluster"

The virtual laboratory is also widely used by young researchers, particularly doctoral students. It should be stipulated that in the wake of the full-scale unprovoked war aggression in Europe in 2022, the educational landscape has been significantly altered, necessitating adjustments in many plans. Despite these challenges, it remains vital for the Ukrainian higher education sector to maintain its resilience and continue its development.

Facilitated by their experience during the COVID-19 crisis, most Ukrainian universities continue to offer teaching to doctoral students through blended formats regarding wartime restrictions. However, it must be admitted that Russian strikes on electricity infrastructure have made research all but impossible. Added to the challenges caused by the COVID-19 pandemic (the loss of everyday contacts at the campus, the lack of social interaction, difficulties in accessing laboratories or other research facilities; organizing online training, theses defense, and supervision; the lack of networking opportunities and doctoral schools underfunding, struggling doctoral candidates' rates increasing) [9], the war has caused new challenges connected with appropriate addressing the needs of such a diverse category of PhD students as doctoral candidates at risk. This includes those who have fled or are at risk of fleeing Ukraine due to the war, those who have remained in the country, including displaced PhD students within Ukraine, doctoral students in refugee-like situations, and Ukrainian doctoral candidates who are refugees abroad. Special attention is required for struggling doctoral candidates and international doctoral students connected to Ukrainian academia.

In the *Researchers at Risk: Mapping Europe's Response Report of the InspirEurope Project* it is defined that researchers at risk include researchers, scholars, and scientists who are experiencing threats to their life, liberty, or research career, and those who are or have been forced to flee because of such threats. Some researchers at risk have recognized refugee status, asylum status, or similar protection status. However, a higher proportion of researchers seeking the assistance of NGOs specializing in the field of scholar protection are outside the refugee process. These researchers are seeking or holding temporary visas/work permits through visiting research/scholar positions at host universities in Europe or elsewhere, outside their home countries [3].

These circumstances motivated the creation of the platform "Transdisciplinary knowledge cluster about resilience strategies for researchers at risk"—Science4Brave Cluster in partnership with the Ukrainian Lingua-Information Foundation of the National Academy of Sciences of Ukraine with the Communal Institution of Higher Education "Lutsk Pedagogical College" of the Volyn Regional Council (a project of the Council of Young Scientists "School of the brave" under the leadership of associate professor Olga Fast) and the Department of Ukrainian Language and Literature of Sumy State Pedagogical University named after A. S. Makarenko (under the leadership of professor Olena Semenog).

The cluster created according to the architecture of ontology-driven L-systems, which provide a robust foundation for teaching and research by combining conceptualization (Σ_{cmO}) with data integration (Σ_{inmO}). These systems classify lexemes ($\gamma : L_T \to S$) and build hierarchical structures to enhance doctoral studies. By leveraging the mappings ($\xi : \Sigma_{exmO} \to \Sigma_{inmO}$), students and researchers gain real-time access to dynamic, context-aware linguistic resources, fostering transdisciplinary insights.

The structure of the Science4Brave Cluster platform is encompassed by addressing research capacity in wartime and post-conflict conditions, ensuring quality supervision and training, and institutional responsibility for supporting early-stage researchers, their societal engagement, academic writing skills, mental health, well-being, and career track. These elements constitute a comprehensive system for developing doctoral education and Quality Assurance, in line with the EUA Innovation Agenda 2026, EURODOC, and EUA-CDE initiatives and developments [4–6].

One of the cross-cutting objectives of the Science4Brave Cluster is to facilitate the integration of advanced European research values into Ukrainian doctoral programmes to achieve sustainability among scholars at risk at Ukrainian regional HEIs. In this context, Ukrainian doctoral students and early-career researchers have analyzed the core challenges that need to be addressed:

- the public is prejudiced against advanced European research values and is unaware of its benefits;
- unsatisfactory research funding based on the leftover principle;
- continuing dependence on Russian-language research journals without quality peer-review procedures;
- lack of meeting academic integrity requirements as a crucial limiting factor for scientific development;
- there is a lack of understanding what are the necessary steps for integrating advanced European research values into Ukrainian doctoral programmes.

Pilot studies conducted among post-graduate students of regional universities of Ukraine show that doctoral students highly value the need to study the strategies of integrating and strengthening the endeavors within the regional university communities in building a culture of social responsibility while ensuring academic engagement and support of doctoral candidates at risk and synchronizing these practices with European policies and standards.

A lexeme *culture of university social responsibility* prioritizes human values and addresses the real needs of Ukrainian researchers while providing early-career researcher-friendly support, both academic and professional. This is particularly crucial given the risks they face, including the threat of a "brain drain" as more scholars emigrate or become refugees.

Working on this lexeme, for example, the following questions were set: (1) what is a socially responsible university in war circumstances? (2) what socially inclusive supports are available within the European and Ukrainian academia? (2) how does quality supervision affect doctoral research capacity strengthening; (3) how does being involved in professional and research peer networking impact the mental health and social well-being of the PhD students and research supervisors; (4) what early-career researcher-friendly supports are available at the community and institutional levels regarding doctoral candidates at risk need diversity; (5) how the good practices of the European universities may be applied to solve the challenges Ukrainian doctoral students at risk face since 2022 and in the other rebuilding times.

In this respect, the Science4Brave Cluster is a project focused on searching for suitable transdisciplinary digital solutions for gaps in doctoral education capacity strengthening at institutional and national levels in Ukraine, primarily due to underestimating its societal dimensions, and synchronizing the Ukrainian practices with the European policies and standards, including helpful initiatives in integrating resilience and sustainability into its academic, research and engagement activities; creating an inclusive and welcoming culture within academia that encourages respect, support, and mentorship.

5 Conclusions

The following conclusions were drawn based on the conducted research:

1. The study demonstrates the potential of applying digital linguistic methods, particularly in the context of the Virtual Lexicographic Laboratory and multimedia dictionaries. These tools provide a novel approach to teaching and researching philological disciplines, making it easier to process and analyze vast amounts of linguistic data using automated systems.
2. The integration of intelligent lexico-conceptographic systems and dynamic ontologies has significantly improved the efficiency of language learning tools and research platforms. The use of artificial intelligence, particularly machine learning and deep learning techniques, enables the automatic processing and conceptualization of linguistic material, making it adaptable to real-time user needs.
3. The use of dynamic ontologies allows the systems to evolve as new linguistic data is processed, enhancing the effectiveness of tools like multimedia dictionaries. These ontologies enable continuous updates to the linguistic content, ensuring that the resources remain relevant and reflective of the latest developments in language usage and media literacy.
4. Digital methods, including the use of statistical, corpus-based, and lexicographic research methods, have a transformative impact on the teaching of philological disciplines. They allow for more interactive, personalized learning experiences, while fostering critical thinking and deeper engagement with linguistic content.
5. The integration of AI-driven methods into doctoral studies has proven beneficial, particularly in terms of academic resilience. Doctoral students are able to interact with large datasets, generate complex linguistic models, and explore the relationships between language and media, further enriching their research.
6. The development of platforms like Science4Brave Cluster and the Multimedia Dictionary of Infomedia Literacy reflects the growing importance of transdisciplinary knowledge in addressing the educational and research challenges of today's globalized and digitized world. These tools foster international cooperation, enhance resilience in educational systems, and help integrate European research values into Ukrainian academic programs, particularly in times of crisis.

Future Work. Building on the findings of this study, future research and development should focus on the following directions:

1. Advancing AI and Ontological System:
   a. Further development of dynamic ontologies to enable better scalability and adaptability for evolving linguistic data.
   b. Exploration of hybrid neural architectures that improve contextual understanding in linguistic analysis.
2. Enhancing Educational Tools:
   a. Expanding the Virtual Lexicographic Laboratory to include multilingual support and cross-disciplinary applications.
   b. Introducing gamified elements and advanced visualization features for enhanced user engagement in multimedia dictionaries.

3. Personalized Learning Through AI:
   a. Developing adaptive AI-driven tools to customize learning experiences for students and researchers based on their unique needs.
   b. Leveraging cognitive services to track progress and offer tailored educational interventions.
4. Transdisciplinary Integration and Collaboration:
   a. Establishing partnerships between international institutions to synchronize methodologies and enhance global usability of Ukrainian linguistic tools.
   b. Incorporating linguistic technologies into broader educational and social research frameworks.
5. Support for Crisis and Resilience:
   a. Using digital linguistic methods to preserve cultural identity and provide educational solutions in crisis scenarios.
   b. Expanding tools like the Science4Brave Cluster to support researchers and students in regions affected by conflict or disaster.
6. Doctoral Research Innovation:
   a. Enabling doctoral students to use AI-driven systems for deeper, more comprehensive linguistic analyses.
   b. Strengthening international mentorship and peer networks to support early-career researchers in challenging contexts.

By addressing these areas, future work can contribute to the further evolution of digital linguistic methods, promoting their application in diverse academic, educational, and societal contexts.

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