Genesis and Predictive Ability of Ecosystem Approach in Education

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Abstract

In recent decades, the educational landscape has been progressively diversifying the world over, including an influx of various new participants and the emergence of new products, technologies, and institutional configurations. This trend is global and triggers a debate on the emergence of comprehensive education ecosystems; however, our understanding of the latter remains fragmented and unstructured. This hinders both the scholarly discourse and fully harnessing the predictive potential of the ecosystem approach. The goal of this paper is to identify education ecosystems' attributes, characteristics, and patterns, and propose an ecosystem approach to studying and modeling both transformational processes in education and the shift toward sustainable development in this domain.

The paper contributes to the conceptualization of education ecosystem based on the principles of open and dynamic social systems. It emphasizes stakeholders' coevolution, a high degree of resource and competency complementarity, participation, and collaborative competition in the creation of innovative educational products. To accomplish the objectives of this paper, we have analyzed the genesis of the education ecosystem concept, traced its continuity with the triple, quadruple, and quintuple helix models and with the innovation ecosystem concept. Consequently, a methodology for applying the ecosystem approach in foresight studies was proposed and for co-designing strategies to accomplish the sustainable development goals in the education domain. The suggested methodology is aligned with the basic principles of the UN Sustainable Development Goal for Education until 2030 (SDG4).

Among other things, the ecosystem approach can be applied to identify data sources, interpret signals of the future, and describe the subject of a foresight study. Thus, we affirm the validity of the ecosystem approach for modeling novel stakeholder interaction formats, delineating the coevolution of social, economic, technological, and cultural trends, and setting fair and socially important priorities for advancing the education domain.

Keywords: educational ecosystem; platform; actors in education; Foresight in education

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Introduction

Over the past few decades the education system has been expanding, becoming increasingly complex and diverse all over the world. Educational programs' content, skill sets, and specializations become more varied (OECD, 2021) along with their delivery formats. Apart from the established, relatively closed and formalized institutions (such as schools, universities, secondary vocational and additional education organizations), there has been significant diversification of institutional formats, and approaches to delivering educational content to the expanding audiences: accelerators, learning resources offered by various thematic communities, business schools, and collaboration platforms (Tomasova et al., 2021).

The growth in these trends determines the need to apply the biological and economic ecosystems metaphor to the education sphere to more thoroughly understand the latter's characteristics and features. Since 2015, the number of publications on the ecosystem characteristics of the education domain has sharply increased. The main research topics are the novel training arrangements and interaction formats between educational institutions and students, in terms of their flexibility, versatility (De Souza Rodrigues et al., 2021), sustainability (Aguilar-Forero, Cifuentes, 2020), and social justice (Niemi, 2021). Many researchers also focus on the issues related to the inclusion of social communities and entrepreneurial structures in education ecosystems (Belitski, Heron, 2017), the development of platforms (Kerres, Heinen, 2015), and the decentralization of educational institutions (Stensaker, Maassen, 2015; Niedlich et al., 2021). There is a growing debate on the optimal configuration of education ecosystems to respond to the demands and challenges of the changing world, develop new competencies and skills while adhering to the principles of efficiency, inclusivity, and accessibility (Wu, 2021).

A number of researchers specializing in the sustainable development of education are stressing the risks of adopting a non-ecosystem approach to transforming education. These include accomplishing only superficial and short-term effects without fundamentally improving the quality of the educational experience, suboptimal use of human resources (teachers and students alike) in the situation of a hyper-intensive transformation, and the disruption of traditional processes without the necessary preparation in terms of value, competences, and psychological aspects (Hargreaves, 2007). Along with this, researchers point to the contradictions inherent in narrowly focused approaches to transforming the education sphere: striving for quick solutions and transferring best practices without taking into account ecological considerations (the instrumentalist approach); evaluating education through the prism of economic growth to the detriment of maintaining a fair social contract in the interconnection of social, environmental, and economic problems (Wulff, 2020).

Despite researchers' high interest in ecosystem processes in education, the conditions for and limits of applying ecosystem optics in this area remain poorly researched. The principles and characteristics of ecosystem participants' interactions, as well as the interface of its components and levels are understood insufficiently. This results in fragmented knowledge about the education ecosystem and complicates the analysis of how well educational service providers match students' demand and communities' needs. The research and forecasting potential of the ecosystem approach to studying the transformation of the educational sphere and its transition to sustainable development cannot be implemented in the absence of the necessary conceptual apparatuses.

According to the research agenda presented in UNESCO reports and working papers, only a broad view of education as a mix of the formal, non-formal, and informal sectors and all involved stakeholders will allow for accomplishing the sustainable development goals through the development of new social practices and by achieving synergies between education and other fields (Sousa, 2021). The UN Sustainable Development Goal 4 (SDG4) is based on an ecosystem vision of the educational process, suggesting sustainable formats for interacting with the environment through reflexivity in creating personal knowledge constructs, maintaining common meanings and shared socio-educational values in local communities, increasing people's social responsibility and awareness, and adopting a holistic approach to meeting global challenges (Inayatullah, 2020).

Taking into account the UNESCO strategy and recognizing the value of the ecosystem view and balanced education concept in accomplishing the sustainable development goals, the objective of this study is to reveal the essential characteristics of all the above elements. Comprehending the disparate set of concepts applied in the ecosystem discourse, reducing the fragmentation in studying the parameters, attributes, and signals of innovation in the ecosystem, identifying various paths to understanding this phenomenon, and choosing one of them as the basis for further analysis seems to be fundamentally important.

The goal of the paper is to describe the characteristics and patterns of the ecosystem to propose an adequate approach to analyzing and modeling the transformation of the education domain based on a comprehensive literature review, conducted using the criteria described below. To accomplish this goal, the paper is organized as follows:

- the first section describes the genesis of the ecosystem approach and the use of the education ecosystem concept in the context of education, innovation, and modern society research;
- the second section addresses the characteristics of education as a complex nonlinear social system, the principles of interaction between its actors, and the exchanges, cooperation, management, and leadership in education in line with complex systems' development patterns;
- the third section summarizes the scope for and limits of applying the ecosystem concept in the field of education and proposes a comprehensive definition of the education ecosystem to clarify the general terms for describing it;
- in the fourth section, a set of principles for using the ecosystem approach to analyze and forecast the transformation in the educational sphere and co-design sustainable development principles for it are proposed.

Research Methods and Sources

The range of sources to conduct a conceptual review was determined based on the snowball and theoretical saturation principles. Papers based on experimental data were selected (comparative and typological studies in education, case studies) along with materials presenting secondary data processing and conceptual research results. At the first stage of the study, Scopus, Web of Science, ScienceDirect, and ResearchGate databases were searched for sources whose titles or keyword lists contained the terms "education/educational" and "ecosystem". The use of the above databases provided an international perspective for studying the education ecosystem concept, with a focus on high-quality publications. The search was supplemented with a selection of highly cited papers from the eLibrary database to cover relevant Russian-language publications.

Next, certain inclusion and exclusion criteria were applied to all publications selected from the abovementioned databases (papers, monographs, conference proceedings). No country, language, or release date restrictions were used. Abstract publications were excluded, including editorials and author responses, along with papers with no full-text access to them. After reviewing abstracts, publications unrelated to education were omitted (such as papers focused on natural, ecological, and biological ecosystems). Thus, the first 23 publications were identified.

Their analysis revealed the main characteristics of the ecosystem development vector in the educational domain and related concepts; this allowed the authors to continue the selection of sources. Due to the close relationship between the educational ecosystem and spiral model concepts, a further search was carried out using the newly identified keywords ("triple helix", "quadruple helix", "quintuple helix"), which yielded 14 more publications.

Since the genesis of the education ecosystem concept was traced to the concept of a complex and dynamic social system, the search for sources to study the relationship between these concepts was conducted using the keyword combinations "complex system in education / complex educational system" and "dynamic social systems / adaptive social systems" (yielded 32 sources). Further searches using the identified properties and development patterns of complex systems to assess their applicability to educational processes in terms of horizontality (keywords "horizontal ties", "hyperconnectivity"), distributed management (keywords "distributed leadership", "distributed responsibility"), and emergence ("emergence", "emergent system") yielded 28 more sources.

Another area to search for suitable sources was identified on the basis of the established continuity of the educational and innovation ecosystems; the search query with the keywords "innovative ecosystem" was used. The search continued until the identified preconditions for justifying the use of the ecosystem metaphor in the innovation economy began to repeat. A total of 14 sources were included in the review. The analysis of this set of publications completed the building of the source base for studying the use of the ecosystem approach in education; it comprised 111 sources in total.

Genesis of the Ecosystem Approach in Education

The concept of education ecology and the ecological approach to analyzing educational processes emerged in the 1960s, in the course of developing the adaptive self-organizing systems theory and searching for ways to make them more stable (Ashby, 1956; Gardner, Ashby, 1970). Such systems are nonstationary in nature and tend to shift toward more optimal behavioral strategies. Their dynamics are described by the law of requisite variety, according to which to effectively solve new problems and meet challenges, the system must be capable of a greater variety of responses than the variety of agitations in the environment (Klir, Ashby, 1991).

The term "education ecology" was coined in 1975 to describe the relationship between educational organizations, key stakeholders, and their social environment (Cremin, 1975). Under this approach, the educational system is seen as a complex integrated phenomenon with a number of ecological niches. Like all living and growing systems, it maintains

a dynamic equilibrium between various unstable states. Innovative transformations, the emergence of new actors, conflicts, and interactions in the system disrupt this equilibrium and push it toward searching for a stable path. Sudden abrupt transitions from one state to another create multiple bifurcation points and attractors.

A detailed and structured description of the educational system ecology from within (from the student's point of view) is presented in (Bronfenbrenner, 1976, 1979). The author identifies four nested systems: microsystem - the core directly responsible for the implementation of the educational process focused on students' interests; mesosystem - a set of environments where students actually live and act; exosystem, comprising formal and informal structures which operate at the level of local communities and set the social context for the educational process; and macrosystem which comprises political, socioeconomic, and cultural institutions (Bronfenbrenner, 1976). Education ecology is focused on both the interaction of students with the four above subsystems and the latter's interaction with each other. For a deep and accurate understanding of what is happening in the educational system, one must take into account the ecological coherence of all elements making up the learning situation, namely its evolutionary mechanisms, actors, and objects, their relationships with the sociocultural context, and the mutual impact of all its subsystems at each level. We are talking not about changing values of educational system variables, but about the system's qualitative integrated transformation, the emergence of new properties and links, and changing appearance. Taken together, these aspects form an ecological model of the educational sector's development, and the ecological approach to studying it, which integrates relevant processes, persons, context, and time (Bronfenbrenner, 1979).

The understanding of interconnected subsystems of the educational process was further improved on the basis of the Enterprise Performance Management (EPM) concept borrowed from economics. Three dimensions of the education ecosystem are identified: macro-dimension, which describes the national and regional cultural context; meso-dimension comprising platforms and organizations, incubators, and entrepreneurial skill centres which provide technical support for the ecosystem; and micro-dimension, i.e., individual actors bringing new initiatives into the system, including teachers, entrepreneurs, and mentors implementing grassroots innovations (McAdam, Debackere, 2018).

The search for strong and significant relationships between the components of the educational and external environments resulted in the emergence of institutional interaction models. In the mid-1990s the Triple Helix Model was proposed: a concept explaining how universities, government agencies, and businesses work together while retaining their traditional functions (Etzkowitz, Leydesdorff, 1995). One of the key aspects of this process is the "mutual blending" of functions, when each actor takes on some of the functions of others. The role of educational institutions in the innovation ecosystem is not limited to knowledge creation, consulting, and human capital development; it is also associated with market initiatives which involve creating venture companies, commercializing useful inventions, developing innovation infrastructure, and launching investment and technology multipliers. Thus, universities become regional entrepreneurship drivers (Schaeffer et al., 2018), which promotes the evolution of their organizational and institutional formats and the emergence of new relations including networking, leadership, conflict, and cooperation (Etzkowitz, Leydesdorff, 2000). Thus, most new ventures launched by universities arise precisely from the social context, i.e., they are created over the course of universities' interactions with local actors. A key role in making the spiral effective and in establishing sustainable cooperation is played by the synchronization of all three components' goals and development levels (De Castro et al., 2000).

Along with the institutional collaboration, the triple helix model also promotes human capital mobility (Dolfsma, Soete, 2006) by blurring the line between the professional and educational spheres. The model suggests that in a mixed reality, education should share the environment, tools, skills, and products with the professional domain. For an individual, obtaining an education is blended with their professional development and with the realization of their research or entrepreneurial interests. The microsystem, i.e., the immediate environment where the educational process is taking place, becomes more diverse and integrates elements which have previously belonged in the leisure or social interaction spheres. For example, computer games and simulations, discussion clubs and makerspaces, excursions and travel, volunteer initiatives, and crowdsourcing are now seen as elements and forms of education.

The mutual blending of and the increasingly complex links between various dimensions of the education ecosystem as well as the exchange of roles between institutions (Cai, Amaral, 2021) occur as education begins to use not only physical, but also virtual, environments, offering opportunities to learn a wide range of activities individually or collectively. The educational process becomes continuous in time and distributed in space, providing a high level of flexibility, personalization, and functionality (Pichugina, 2015). The educational environment is customized and adapted to the student's specific needs and demand and to the local context, thus significantly expanding both the micro- and meso-dimensions of the education ecosystem.

Subsequent studies described how the triple helix model was adapted to the regional context. In particular, researchers noted that the role and importance of the model's specific components may vary from one regional system to another: if in some systems government efforts to commercialize research and development (R&D) is the main driver, in others an endogenous strategy emerges, with a predominance of bottom-up initiatives (Khamidulin, 2018).

Over time, the understanding of how education contributes to dealing with current social problems developed and social variables were introduced into the model, which had not been explicitly mentioned previously (Afonso et al., 2012). An example is the incorporation of "grand challenges" into educational content and in the targeted development of students' practice-oriented experience (Yun, Liu, 2019). After initial experience was accumulated (Berger et al., 2013), a growing interest in integrating teaching strategies with practical activities to solve current global problems emerged. This promotes the development of social links and immerses learners in the complex dynamics of the real world (Nowell et al., 2020). The phenomena that in the original model (Bronfenbrenner, 1976, 1979) belonged in the macro-system and affected the educational process only indirectly (by influencing students' perceptions and values), "in one click" became an integral part of the actual reality and were integrated into educational content and woven into everyday communication.

The Quadruple Helix model takes into account the role of society as a separate component. Society gets an opportunity to express itself in the education ecosystem; it no longer remains just a consumer of educational products or a stakeholder whose interests are taken into account when educational policies are shaped, but becomes an actor offering and disseminating new solutions (Carayannis, Campbell, 2006). Society is directly involved in the promotion of the knowledge and innovation culture and the maintenance of infrastructure for the creation, transfer, and commercialization of knowledge and innovations (Colapinto, Porlezza, 2012). Against this background, educational organizations are increasing their role in the implementation of innovations based on social values and needs through network interactions (García-Terán, Skoglund, 2019). Acting as both co-developers and collaborators, communities lay the foundation for user-centred design, facilitate and accelerate dynamic processes, and promote open innovation policies. At the same time collective responsibility for improving the education ecosystem comes to the fore: social development in a specific territory becomes the responsibility of partner networks, which include educational service providers (Kremneva et al., 2020). The partnership education ecosystem type implies the presence of such important aspects as knowledge transfer in an open environment and the fair allocation of results across the entire ecosystem (Karalash, Baumöl, 2019).

One of the consequences of society's participation is grassroots innovations, or bottom-up initiatives by individual actors reflecting their personal needs, motives, and interests in the educational field (Miller et al., 2018). Such initiatives contribute to the ecosystem by increasing awareness of local needs, facilitating the attraction of resources and the provision of support at the community and local network levels. Balanced development of the education ecosystem requires synchronization and mutual adaptation of top-down and bottom-up initiatives to make it (the ecosystem) dynamic, non-linear, and organizationally wholesome (Schophuisen, Kalz, 2020).

Thus, compared to the triple helix and earlier approaches, the quadruple helix model shifts the focus from system elements' functions to their interactions and through this to the introduction and dissemination of innovations.

The subsequent development of institutional models is associated with the inclusion into the education ecosystem of the environment in the broadest sense, in the form of environmental requirements, demand for sustainable development of the biological system, and taking into account the interests of environmental organizations and activists. This leads to the emergence of the Quintuple Helix model (Carayannis et al., 2012), where the ecological subsystem, while not seen as a component of the education ecosystem as such, is integrated into the learning and knowledge transfer mechanism in the form of sustainable development goals for the external (biological) and internal (social) environments (Crilly et al., 2020). By integrating these issues into educational programs, the education ecosystem responds to increased public attention to the human impact on the environment.

The development of spiral models reflects the rapid advancement of views on the education ecosystem components. If initially only the three most obvious actors directly involved in the knowledge creation, transfer, and commercialization processes were included in this ecosystem, over several decades the model was extended to integrate many new, unobvious players, who are in one way or another interested in the results of the innovative educational process and willing and able to contribute to this process. The principles of increasing ecosystem diversity described above allow one to suggest that the emergence of new actors is imminent in the education ecosystem, while its structure cannot remain constant. Due to its complexity and variability, educational system tends to become more diverse in response to changing demand. The roles originally played by traditional institutions are being taken over by new actors who, through the use of digital educational platforms, are transforming educational

mechanisms making them more open and transparent. Building up the spiral by mechanically adding new players to the education ecosystem has demonstrated its limitations, so a more comprehensive approach is required to describe the growing number of its participants.

Though the spiral models focus on actors, they describe not just the growing complexity of the latter's objectives, roles, and functions, but also the new emerging connections between them. The density of these actors' interactions increases in n-dimensional progression, describing which requires modeling an n-dimensional interaction environment where n is an unknown number of elements. One approach to describing the changing relationships between actors not specified in advance is to apply the complex systems theory, discussed below in the context of the education system.

Complexity, Emergence, and Openness in Educational Systems

Complexity theory has proven its effectiveness in explaining novelty, order, and evolution in various domains and systems, including socioeconomic ones (Eve et al., 1997). It analyzes relations in all their complexity, mutual conditionality, and emergence, i.e., the ability to generate new phenomena and specific organizational forms (Harvey, Reed, 1997; Wan, 2016). To assess the applicability of the complex systems theory to education, we will consider their key properties and roles in the educational environment. This will allow us to link such systems' development patterns to the changes in the education domain.

The first property of complex systems is nonlinearity, i.e., sensitivity to minor random fluctuations and the ability to radically change development paths in response to external impacts. The system state cannot be fully predicted based on the initial conditions due to nonlinear effects such as crises and bifurcations. In the field of education, at the micro-level we can talk about nonlinear academic paths and successes of individual students due to the so-called butterfly effect in the scope of overall academic performance (Akmansoy, Kartal, 2014). The educational path is set by minor deviations in the completion of specific educational modules, taken together (Newell, 2008). At the meso-level, educational institutions, responding to the social context, change their organizational form and the contours of their activities in such a way that their success cannot be predicted on the basis of the initial conditions. For example, university funding arrangements depend not only on the immediate changes in educational policy and accreditation systems, but also on the dynamics of socioeconomic inequality, student debt, and the labor market. At the macro-level, the division of resources between individual segments of the education sector is equally uneven, since some of them benefit from globalization, international cooperation, and mobility, the emergence of new media, and changing demand for competences by society (Navarro-Bringas et al., 2020).

The second property of complex systems is information asymmetry: the uneven distribution of knowledge between the system parts that have different levels of information certainty about an interaction subject. The educational domain provides numerous examples of information asymmetries between organications and target audiences, caused by unequal access to information sources and self-presentation opportunities in the system (Teichler, 2006). In particular, in the "student-university-employer" triangle, the latter does not really know how accurately university diplomas reflect the actual quality of graduates' training, which can demotivate universities to make efforts to improve students' skills. As a result, universities prefer to invest in promoting their status and brand, which are more visible to employers and therefore increase graduates' chances of finding jobs (Tagarov, Tagarov, 2018).

The third property of complex systems is openness, i.e., the ability and inclination to continuously interact with the external environment and exchange resources and information via weak links with individuals and organizations operating in other contexts and activity areas. All this promotes diversity and the emergence of alternative and interdisciplinary approaches to problem solving. At the same time, intrasystem processes become dependent on the system elements' interaction with the external environment and cannot be adequately explained without taking into account outside developments. Educational systems belong in the open systems group since their boundaries are permeable to the external environment: they expand through content providers' use of technological tools, taking into account the social context of learning, areas of leisure and professional development and a wide range of stakeholders (Cunningham, 2001). Educational platforms take over some of the functions associated with assessing students' progress and providing feedback to them, while cultural venues are responsible for their socialization. The role of technological educational platforms (edtech) in schools' and universities' operations has significantly increased with the massive transition to distance learning during the COVID-19 pandemic.

Another openness attribute is the active interaction of the educational system with the periphery: processes, phenomena, and objects not directly related to education but capable of influencing the changes occurring in this sphere (Danilina, Rybachuk, 2018). For example, practitioner communities (employers, professionals) can provide quick support in developing new skills, while makerspaces facilitate the

exchange of experience between technology enthusiasts and customers – the spontaneous transfer of specialized skills and abilities to creatively solve specific problems.

The fourth property of complex systems is hierarchy and structural complexity, i.e., numerous levels, linked elements on each of them, and protocols for their interactions (Snowden, 2003). Hierarchies and subordination levels in the educational system reflect the order of municipal, regional, and federal levels of government, structures, the taxonomy of educational units' formal types, and the regulation of their activities based on strict educational standards. The educational system is permeated with interdependent ranking, certification, licensing, and accreditation algorithms constantly supplemented by new protocols for collaboration, regulation, control, and reporting, which explains its structural complexity.

Thus, the educational system belongs in the complex systems category due to having certain properties, namely nonlinearity, openness, information asymmetry, and hierarchy. This suggests it can develop in accordance with complex systems laws which explain the transformations occurring within it.

One of the key development patterns of a complex system is the constant growth of its hyperconnectivity: the rapid direct contacts between participants. At the same time, numerous and varied weak links emerging in a centralized system increase its stability and flexibility (Osberg, 2002). Weak links are manifested in the interaction with peripheral parts of the educational domain, such as, for example, employer communities, makerspaces, and cultural venues and involve the informal or sporadic emergence of common initiatives. Hyperconnectivity is determined by the quality of horizontal information flows, their content, and the ability to overcome the segments' and subsystems' boundaries. Feedback loops between all actors are of particular importance.

Hyperconnectivity in the educational system involves multilateral knowledge transfer, joint learning (Cai et al., 2020), and the constant involvement of professionals with unique competencies (Barokas, Barth, 2018). This creates a shared vision, facilitates the development (and forecasting) of the educational environment, enables peer coaching and professional growth of teachers, and promotes the transformation of school or university practices. Through this collective reflection arises along with exchange of views and the exploration of new approaches. Moreover, these activities do not necessarily occur in the framework of methodological associations at a single educational institution, but can bring together teachers from different institutions on voluntary basis. Hyperconnectivity makes possible the rapid implementation of best educational practices through a network of interpersonal and interorganizational interactions (Koul, Nayar, 2021), quickly achieving results in terms of rapid and effective solving of emerging problems and the application of innovations by all process participants including management, teachers, and parents (Lemke, Sabelli, 2008).

The growth of hyperconnectivity is associated with such complex systems characteristics as the emergence of ordered structures through the self-organization of agents (Törnberg, 2017). Each element of the system has a fluid identity: its role and behavior change when it comes in contact with other elements, triggering a chain of changes in the response behavior of other links, and provoking the emergence of unplanned patterns (Audouin et al., 2013). Subsystems and clusters of elements are spontaneously created and develop their own lines of behavior (Kuosa, 2016). Emergence is a process of ordering chaos: the birth of properties and structures which could not be expected or predicted based on the known attributes of individual system components and external forces (Iansiti, Levien, 2004). In contrast to an emergent one, an ordinary structurally complex system can be precisely defined at any level: each of its elements can be accurately described and the cause-and-effect relationships between them can be modeled and predicted (Törnberg, 2017). The emergent complexity of educational systems is evident in the presence of numerous self-organizing groups within them, which pursue different goals in often unpredictable ways. These include individual actors (students, teachers, managers), communities (classes, schools, universities, teacher associations, etc.), and external structures (research centers, consulting and other companies) (Rogers et al., 2013). Students' activities are affected not just by the curriculum and assessment systems, but also by cooperation with other students. This co-creation yields new ideas, leads to educational projects taking unplanned development paths, and even to changes in educational paths or specializations.

At a higher level, complex systems are characterized by distributed leadership and responsibility. The distributed management phenomenon is associated with changing the principles of process regulation in the system whose transformational potential is hampered by excessive centralization and the unidirectional transfer of initiatives, goals, guidelines, and rules from the management to lower levels. In a complex and heterogeneous environment, it is the decentralization elements which contribute to increased involvement of all stakeholders in making important decisions (García, 2019). Educational systems on the one hand have channels for formalized top-down transfer of codified knowledge and attitudes, while on the other, students, teachers, and managers act as links in the social chain which develop and reassemble educational formats, thus promoting innovation and diversity (Erçetin et al.,

2015). This achieves a balanced distribution of management functions between different levels of the system, and helps to balance national, regional, and local interests.

Distributed management can also be performed by specialized non-governmental organizations. They create special communities to support and disseminate initiatives with a strong social dimension, find authors of socially important educational projects and provide them with financial or expert support, and build networks of organizations for joint development of solutions that change the educational landscape. Such initiatives are implemented jointly with schools, universities, corporations, public associations, the media, and other influencers, provide consulting support to them, and lead to the emergence of an extensive network of leaders and ambassadors of change (Wu, Lin, 2020). Maintaining the right centralization/decentralization balance is an important aspect of implementing educational reforms. Involving teachers in planning, empowering school management and local authorities facilitates the targeted meeting of community demand and promotes dynamic, high-quality cooperation between stakeholders and authorities. For example, in Finland, over the course of regular national-level curricula revision, only the core of the curriculum (the basic framework for all hierarchy levels) is determined, while the final standards and procedures are set locally (most often at the city level) jointly with teachers, parents, and other stakeholders, taking into account the local context (Niemi, 2021).

The allocation of management functions is closely related to the distributed responsibility and distributed leadership concepts. The first arises from facing complex and systemic challenges, dealing with which requires not just mobilizing the available resources, but allocating them across the system in the most effective way. In education, these complex tasks include, among others., ensuring fair and equal access to education, which implies preventing early dropout, increasing the attractiveness of higher and specialized secondary education, and facilitating a smooth transition between levels, i.e., increasing the importance and responsibility of various structures (Flynn, 2020). Distributed leadership is based on the interaction of formal and informal leaders at all levels of the hierarchy (Rikkerink et al., 2016) and setting an egalitarian vector for the development of the system. This principle takes into account the diversity of individuals with leadership potential who understand the essence of ongoing changes and can make decentralized decisions (Şentürk, Kılıçoğlu, 2016). In education, distributed leadership provides the basis of a participatory approach to involving local communities in the activities of educational organizations (Hoppes, Holley, 2014). It can take the form of encouraging the exchange of tacit knowledge and skills, helping to organize and equip the learning process, and implementing practice-oriented projects (Hautamäki, 2006; Herselman et al., 2019). Researchers especially focus on the allocation of responsibilities for accomplishing strategic sustainable development goals in education between individuals, institutions, and regulatory authorities (Boeren, 2019).

Thus, development patterns of complex systems provide a key to describing the transformation of the education sphere. However, a complex system is not yet an ecosystem since the interaction of actors in it remains atomic, their mutual adaptation may remain low, and the coevolution mechanism may not be fully implemented. This section described basic properties and patterns of complex systems in education; now we will move on to the ecosystemic transition, specifically the signs of an educational system's transition to an education ecosystem and, accordingly, the limits for applying ecosystem optics to studying the educational domain.

Ecosystemic Transition in the Education Sector

The key to a comprehensive and structured description of an ecosystem in terms of interactions in the socioeconomic sphere is provided by the innovation economy (Adner, Kapoor, 2010). An "innovation ecosystem" is focused on the creation of innovations and based on the community's links with a focal firm or platform (Talmar et al., 2020). These links emerge due to actors' joint participation of in value creation and affect the use of resources, information flows, and the allocation of roles (Jacobides et al., 2018). As a result, actors' specializations increase and their functionality adapts to the objectives of affiliated structures. The relationships between people, their use of knowledge, and resources are constantly adjusted in a trial-and-error manner, leading both to incremental changes and deep transformations (Oksanen, Hautamäki, 2015). Such mutual adaptation in a certain spatial context is a necessary condition for the existence of an ecosystem, which ensures accelerated knowledge creation and technology development and ultimately leads to joint creation of innovative value by specialized actors which would be impossible without collective effort (Hage et al., 2013). Meanwhile each individual actor's value is not realized outside the ecosystem, so their survival depends on others (co-creation and joint survival) (Clarysse et al., 2014).

Evolving systems are based on high modularity as well as resource and competency parallelism; these traits facilitate the rapid adjustment of actors to each other (McKelvey et al., 2012) and their complementarity, i.e., the cohesion of interests and productive interactions. Complementarity implies having, maintaining, and creating new co-specialized assets in the course of value creation. Complementarity

can be universal (the actor is integrated into the operations of a wide circle of people) or specialized (the actor's resources and competences only match the needs of a highly specialized group) (Kapoor, 2018; Ganco et al., 2020). An example of universal complementarity in education is organizing educational video conferences and webinars regardless of the nature of the educational event. Solutions such as learning management system (LMS) platforms can be adapted to a certain training level or customized to meet the needs of a particular institution.

The widely diverse affiliations of actors and organizations as well as specialized complementarity speed up the evolution of ecosystems (Kapoor et al., 2021). Because of complementarity, each actor is involved in many different, partially overlapping structures and different types of relationships (relational pluralism), therefore, each actor plays several roles simultaneously. The knowledge and skills, goals, and behavior patterns inherent in different roles increase the diversity of actors, while the ecosystem itself becomes more heterogeneous due to the involvement of representatives of various industries (Nambisan et al., 2019) including culture, entertainment, technological innovation (edtech), open environments, and so on. Its further transformation is determined by the institutional, cultural, and regional diversity and the various kinds of cooperation it facilitates.

Researchers emphasize that in innovation ecosystems cooperation and competition take place at the same time (Bogers et al., 2019); the balance between them is determined by how much the actors' personal goals match or contradict each other. Cooperative interaction stems from complementary efforts to create value, while competitive motives arise from the desire to maintain market niches. Each actor in the ecosystem must find not only ways to contribute to joint value creation, but also the means to appropriate their share of the value (Radziwon et al., 2017; Chesbrough et al., 2018).

Taking into account the above assumptions, one can conclude that the term "ecosystem" is applicable to the educational sphere. Its particularly important aspect is the mutually beneficial cooperation of individuals, institutions, and educational structures – members of joint creativity networks. At the same time, competition increases in all segments of the educational market due to diversity of its participants and their behavior strategies.

The presented conceptual analysis and the assessment of the ecosystem approach's applicability in education allow us to suggest an original definition of the education ecosystem: it is a complex, dynamic, and open social system, the participants of which evolve and join efforts to create new educational products, making use of the wide diversity and high complementarity of their resources and competences. Many direct links quickly arise between the actors in the education ecosystem at different levels (hyperconnectivity), leading to the emergence of new educational formats and products which transform the system as a whole (emergence). Effective regulation of the education ecosystem is based on the distribution principle (of leadership, responsibilities, and management).

Now let us consider how the above properties of the educational sphere and the features of its actors' interactions determine the productivity of the integrated ecosystem approach for studying innovation processes occurring within it.

Ecosystem Approach to Studying and Forecasting Innovative Processes in Education

The interconnection of properties and patterns of the educational sphere determines the characteristics of innovative processes taking place in it and the need to adopt an ecosystem approach to study them.

First, present-day educational systems show a tendency toward radical transformation, going beyond their boundaries (Lane, Maxfield, 2018). Technological and social innovations are redefining the scope of sectors, pushing the players to dynamically diversify their activities. An example is edutainment (blending educational and entertainment content) which promotes the partnership of public spaces and cultural venues with educational organizations and developers of mobile applications and VR solutions with teachers. New mechanisms for delivering educational products to students are emerging, such as art residencies, case championships, living labs,and so on, which in turn give new roles to the education ecosystem actors. All these processes must be analyzed in their dynamics.

Second, new educational solutions often emerge bottom up, while qualitative transformations occur when sufficient diversity is accumulated at the lower levels of the system (Vanhaverbeke, Cloodt, 2006; Zhai et al., 2021). Combining the organic growth of innovations in grassroots communities with providing structured support from the top helps to implement initiatives sustainably (Hung et al., 2019). It would be impossible to study innovation dynamics without considering both these vectors (top-down and bottom-up) and their relationship.

Third, due to the inertial factor in complex systems' development, the diffusion of innovations in education is accompanied by the formation of ecological niches around new products (West, Wood, 2013). Around any technology or solution emerges a system of interconnected services, providers, and stakeholders. The more stable these emerging niches are, the higher the innovation's chances to take root in the ecosystem (Civís, Díaz-Gibson, 2021). Studying transformations in the education sphere, one must consider how different subsystems com-

prising various actors simultaneously obtain a new development vector.

Fourth, there is a connection between participation, sustainability, and solving complex innovation-related problems in education. It is impossible to make human-centric decisions if a significant proportion of stakeholders are excluded from the transformation process, and no institutional cooperation occurs (Schnack, 2008). The study of integrated innovation in education implies a participatory approach, i.e., taking into account the opinions and interests of specific actors when implementing changes and making decisions (Mahoney et al., 2021). Multi-stakeholder partnerships play a key role in operationalizing education for sustainable development, involving the community in lifelong learning (Collective, 2020) and companies - in meeting the green economy demand, making practice-oriented educational programs more accessible (Bonal, Fontdevila, 2017), and making policy shaping more evidence-based, transparent, and accountable. Participation plays an equally important role in monitoring the progress in achieving sustainable development goals in education by the community and its more active members on bottom-up basis. Such monitoring allows the community to identify sensitive areas, find out whether various initiatives are actually implemented, assess marginalized groups' situation, and draw attention to the level of human rights compliance (Krupar, Taneja, 2020).

Thus, studying innovation in the education sphere involves analyzing its ecosystem characteristics and promotes the application of ecosystem optics. This approach is simultaneously the object of research, a principle for building the source base for it, and a tool for analyzing and interpreting the identified patterns and assessing their social significance. However, the cognitive potential of the ecosystem approach has a number of limitations.

Ecosystem Approach to Building a Source Base for Research

The ecosystem approach implies involving experts, experienced users, community representatives, and platforms in the identification, selection, and evaluation of signals about innovative changes taking place. The quality of results is determined not only by the amount and reliability of the analyzed information, but also by the variety of its sources and perspectives from which data was selected and accumulated. The key to solving complex organizational problems often turns out to be in broadening the range of contextual information about the object under study (Davis, Sumara, 2014). Reaching out to a wider community of practitioners, especially non-metropolitan ones, also appears to be a productive approach in terms of generating more diverse ideas and detecting signs and signals of change (Kim et al., 2013). Analyzing weak links enriches the study of educational innovations, since they allow one to discover unobvious drivers of change and connect signals from numerous related fields. The platform principle also plays an important role in building a source base: it allows for a controlled and structured collection of observations from participants sharing certain common characteristics (Hiltunen, 2011).

From a methodological point of view, it is important not only to involve stakeholders with different backgrounds in the study, but also structure their input in such a way that each of them would complement the common information base (Warnke, Schirrmeister, 2016). The inclusive evidence principle helps one to solve this problem, according to which actors must independently determine their position in the ecosystem; a circle of third parties with similar interests emerges, cooperating with whom seems to be in order. The overall structure unfolds as the actors discover new links, which allows them to gradually overcome the fragmentation of the source base (Nugroho, Saritas, 2009).

The use of the ecosystem approach to select research sources has a number of limitations associated with the excessive amount of information, possible duplication and irrelevance of data and signals. This raises the issues of labor-intensive monitoring and the need to filter the collected materials when the amount of incoming data begins to exceed researchers' cognitive abilities. Also, people have different ideas about which sample size should be considered sufficient, which can lead to conflicting approaches to signal filtering by different researchers.

Ecosystem Approach to Interpreting Patterns, Trends, and Signals

The ecosystem approach allows one to outline the contours of an in-depth multidimensional analysis of the connections between trends, signals, and patterns under study, including the use of sociograms and conducting cluster and network analysis of the diffusion of innovations.

Profound changes in education are caused not so much by new products and solutions as by actors' attitude toward them. These changes affect different subsystems, each with its own set of established social practices, goals, management styles, and perspectives (Carbonell et al., 2015). Some initiatives are implemented by horizontal communities and through informal interactions. The same innovations applied in different systems of actors' relations lead to different developments, so incoming signals cannot be adequately interpreted without understanding the interconnection of interests, resources, and functions in the education ecosystem.

The ecosystem approach to interpreting information allows one to identify and summarize communities' aspirations and demands and hidden but important motives for resisting trends. It also permits one to reveal the links between surface signals and deep motives as well as the attitudes of ecosystem participants (Milojević, Inayatullah, 2015). It further provides a range of analytical tools needed to adequately respond to external complexity. According to the postulated principle of studying complex systems (McKelvey, 2022), only internal diversity can provide an adequate response to heterogeneous external conditions; only internal degrees of freedom can overcome external ones; internal complexity balances external complexity, while internal fractality compensates for that of the external environment. Thus, multiple interpretations of information coming from outside of the ecosystem allow one to eliminate and integrate into the analysis its inconsistency, redundancy, and ambiguity.

The main limitation of applying the ecosystem approach to interpret signals is the difficulty of weaving varied motives, metaphors, and descriptions into a single narrative. Each participant's individual narrative directly depends on the ecosystem niche they occupy, so forging a dominant frame on their basis is fraught with losing unique insights while the result will still remain fundamentally subjective. Along with this, some participants' deep-rooted but outdated attitudes conflict with the current sociocultural, technological, and economic realities, which also complicates interpretation.

Ecosystem Approach to Describing the Object of Study

The main result of studying innovation processes is forging an image of the future education ecosystem, including its ecological niches (sets of related services, products, channels, and distributors) that will emerge around innovative educational solutions; their consumers and providers; the mechanisms for meeting local communities' demand; and the evolution of roles of, and links between, all actors in the event a particular trend is implemented. Different scenarios can lead to the emergence of new interaction environments in the ecosystem, new ways of applying, adapting, and disseminating new solutions, new platforms and communities emerging around them, and their development paths (Rogers, Euchner, 2022). This thesis is presented in a number of studies whose authors note the need to track the dynamics of innovation clusters and map the links between them, including visualizing actors' positions and roles on a systemic map of changes, new niches, and collaborations in the innovation ecosystem (Borch et al., 2013).

A limitation of applying the ecosystem approach to describe the object of forecasting is the fleeting nature of the latter. The future scenarios we build constantly change when they are not static and collide with each other. Feedback loops force stakeholders to reframe problems and rethink their future roles and niches in the ecosystem; all this makes the forecasts extremely labile, requiring constant revision and addition, which complicates making managerial decisions.

Discussion

The paper aimed to contribute to the development of ecosystem optics for analyzing transformations in the educational sphere. The borrowing of the ecosystem metaphor was due to the need for an integrated approach to these transformations against the background of the increased cohesion, horizontality, and adaptability of the educational sphere. At the same time, studying the transition of a complex adaptive system into an ecosystem remains a non-trivial task: the very scientific viability of using the term "education ecosystem" to refer to a special case of an innovation ecosystem is often called into question. Critics of this approach point to the vagueness of the term and of using it in relation to various entities ranging from corporate and university ecosystems to regional innovation clusters and digital platforms (Isenberg, 2016). In particular, it is noted that the "innovation ecosystem" concept is extended to cover areas which have traditionally been adequately described in terms of clusters, triple helixes, or innovation systems, without sacrificing either meaning or research productivity (Oh et al., 2016).

Nevertheless, it appears that intentionally designing socioeconomic systems does not come into conflict with seeing them as randomly developing biological ecosystems guided only by the forces of natural selection, where innovations are random and evaluated solely from the point of view of their benefits for specific individuals (Kuckertz, 2019). On the contrary, in social systems, competition is regulated by norms, values, and institutions, which shift the effects of actors' interactions toward greater benefits for the system as a whole (Mars, Bronstein, 2018). Finally, if in a biosystem engineering solutions are always local, in a social system successful practices and innovations can be disseminated and adapted for the benefit of other institutions, scaled from the local to the global level, or reconfigured for a different sociocultural context (Papaioannou et al., 2007).

The noted incompleteness of the metaphor and the vagueness of concepts make the cognitive value of the ecosystem concept in the field of education debatable, while our objective was to highlight the ecosystem optics' components which can improve the research toolset. We argue that for the purposes of describing artificial ecosystems, the ecological axiom can be partially modified and adapted (Ritala,

Almpanopoulou, 2017). Meanwhile the education ecosystem concept can be equally divorced from both the classic complex system and the biological ecosystem, and described as an independent phenomenon (Peltoniemi, 2006). The intermediate position between being intentionally designed and having an evolutionary nature makes the innovation ecosystem concept a productive tool for studying social phenomena, provided there is a clear understanding of which of its elements can be designed and which are self-organizing in nature and develop according to co-evolution logic. It must also be understood which ecosystem characteristics should be preserved in the new concept and integrated into its toolset as reflecting current educational trends. First of all, these properties include high diversity and horizontality.

The increased horizontality manifests in the development of the open innovation system in education: crowdsourcing, open licenses, and various agreements which allow one to combine different ideas to develop new products and services (Megahed, Ghoneim, 2022). This can also include actors' focus on finding external partners to create value, the strengthening of horizontal links in the scope of collaborations, exchange of experience, development of personal brands, and so on. (Nadler, 2019). When the role of education in achieving sustainable development goals is assessed, emphasis is also placed on local horizontal interactions, both in terms of involving students in peer-to-peer solving of social problems (Westheimer, 2020) and the joint implementation of educational innovation initiatives aimed at achieving sustainability in the local community (Raj et al., 2022).

Increased diversity becomes key in the situation of high uncertainty and dramatic socioeconomic and technological shifts as well as at the early stages of implementing new projects when various alternatives and points of attraction still exist - i.e., in typical conditions for the transformation of the educational sphere. According to the quintuple helix model, innovation processes in education are affected not just by actors directly involved in the creation, transfer, and commercialization of knowledge (universities, government, and businesses). Other players (such as communities, social infrastructure developers, cultural figures) also contribute to, and are interested in, the emergence of new solutions for the educational sector. This interaction network increases diversity and accelerates change. The latter, in turn, hinders the operation of selection mechanisms: the rapid emergence of innovations does not allow any of them to become a paradigm, a part of the routine process, and create stable and effective activity patterns. Since diversity and novelty become the norm for the work of any researcher, ecosystem properties of the educational domain give rise to many contradictions, both at the level of studying and understanding as well as managing and developing it.

In the situation described above, applying the ecosystem approach allows one to answer a number of complex questions. How sensitive is the education ecosystem in its current state and condition to diversity? Would increasing diversity at the grassroots level be sufficient for (re)launching evolutionary mechanisms or would it require implementing an active support and promotion policy? What exchange arrangements must be made to accelerate innovation? What are the costs of over-supporting some areas at the expense of others? Can a favorable level of the educational environment's permeability be determined, and of actors' integration into the system from its periphery? How does one achieve the adequate degree of participation in carrying out educational reforms and implementing innovations?

Conclusion

Modern models assign major roles in the innovative educational process not only to actors directly involved in knowledge creation, transfer, and commercialization (universities, government, and businesses), but also to other players (such as communities, developers of social infrastructure, and cultural figures) who contribute to and have an interest in the development of new phenomena in education. The educational domain is increasingly acquiring complex social systems' features (which follow development patterns characteristic of various other similar systems) including nonlinearity, information asymmetry, emergence, structural complexity, openness to external environment, distributed responsibility, and hyperconnectivity. At the same time, the educational sphere also has ecosystemic properties manifested in its participants' interactions, namely the co-evolution of actors, the obvious complementarity of resources and competencies, grassroots dynamics, highly permeable boundaries, increased participation, and the emergence of ecological niches.

Taken together, all these characteristics set the transformational vector of the education system and profoundly change the principles of interactions between participants in innovation activities: their agency increases, while geographical and disciplinary boundaries lose relevance, which dictates the need to apply new approaches to researching it. Firstly, one must understand what configuration the modern education ecosystem is obtaining to be able to project it into the future and increase value for all stakeholders; and secondly, one must understand how the ecosystem view of the transformational processes in the educational sphere helps to predict

its future state and take an active part in the joint mapping of sustainable development paths.

The ecosystem approach to studying innovation processes and forecasting changes in education is proposed as a new toolset, expressed in the trinity of principles: for building research source bases, interpreting patterns, trends, and signals of change, and describing the object of study. At the same time, one must strive to increase the diversity of sources and analysis tools by involving the periphery, through deeper contextualization taking into account multiple layers, strengthening the incorporated structure mechanisms, and considering weak links. Maintaining diversity becomes a key research principle, since it allows one to identify deep and unobvious relationships between individual, institutionally autonomous phenomena in education. Diversity does not give rise to, but on the contrary, overcomes the fragmentation of visions of the future, because it helps to trace the co-evolution of social, economic, technological, and cultural trends.

The study may be concluded by acknowledging the productivity of the ecosystem approach for setting fair and universally important priorities for the education ecosystem's development and providing a more comprehensive understanding of the innovation agenda. It encourages greater participation in building alternative future scenarios, ultimately increasing their likelihood and viability.

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