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SUSTAINABLE EDUCATION IN NATURAL SCIENCES, ECONOMICS AND TECHNOLOGY

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ABSTRACT. *The sustainability of knowledge is a critical factor for natural sciences, technology and economic education, as it is directly linked to the creation and management of innovation and the support of sustainable development. The article examines the dimensions of knowledge – explicit and tacit – and their role in the learning process and in educational ecosystems. This study adopts a qualitative research approach based on a narrative literature review and conceptual analysis. It synthesizes existing literature on knowledge creation, knowledge management, sustainability, and educational systems in order to explore the role of sustainable knowledge in modern education. The importance of knowledge management and the preservation of intellectual capital in educational organizations is analyzed, as well as the human, organizational and environmental factors that influence the transfer and exchange of knowledge. In addition, the relationship between knowledge, technology, innovation and sustainable development is explored, with an emphasis on the challenges of less developed countries and the transition to a global knowledge economy. The framework of the knowledge economy is presented and the role of education, innovation and information technologies as fundamental pillars for sustainability is highlighted. Finally, it emerges that the success of educational organizations depends on their ability to create, disseminate and utilize sustainable knowledge, creating a competitive advantage and contributing to the formation of creative, innovative and socially responsible citizens.*

Keywords: *Sustainability, Knowledge, Education, Technology, Natural Sciences, Economics.*

ABSTRAK. Keberlanjutan pengetahuan merupakan faktor penting bagi pendidikan ilmu pengetahuan alam, teknologi, dan ekonomi, karena secara langsung terkait dengan penciptaan dan pengelolaan inovasi serta dukungan terhadap pembangunan berkelanjutan. Artikel ini mengkaji dimensi pengetahuan – eksplisit dan tacit – dan perannya dalam proses pembelajaran dan ekosistem pendidikan. Studi ini mengadopsi pendekatan penelitian kualitatif berdasarkan tinjauan literatur naratif dan analisis konseptual. Studi ini mensintesis literatur yang ada tentang penciptaan pengetahuan, manajemen pengetahuan, keberlanjutan, dan sistem pendidikan untuk mengeksplorasi peran pengetahuan berkelanjutan dalam pendidikan modern. Pentingnya manajemen pengetahuan dan pelestarian modal intelektual dalam organisasi pendidikan dianalisis, serta faktor-faktor manusia, organisasi, dan lingkungan yang memengaruhi transfer dan pertukaran pengetahuan. Selain itu, hubungan antara pengetahuan, teknologi, inovasi, dan pembangunan berkelanjutan dieksplorasi, dengan penekanan pada tantangan negara-negara kurang berkembang dan transisi menuju ekonomi pengetahuan global. Kerangka ekonomi pengetahuan disajikan dan peran pendidikan, inovasi, dan teknologi informasi sebagai pilar fundamental untuk keberlanjutan disorot. Pada akhirnya, terungkap bahwa keberhasilan organisasi pendidikan bergantung pada kemampuan mereka untuk menciptakan, menyebarluaskan, dan memanfaatkan pengetahuan berkelanjutan, menciptakan keunggulan kompetitif, dan berkontribusi pada pembentukan warga negara yang kreatif, inovatif, dan bertanggung jawab secara sosial.

Kata Kunci: Keberlanjutan, Pengetahuan, Pendidikan, Teknologi, Ilmu Pengetahuan Alam, Ekonomi.

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INTRODUCTION

The concept of sustainable in education has three main approaches. The first focuses on its definition, history and application. The second refers to teaching through sustainability, using the concept as a way of seeing the world and understanding an issue. Finally, we can teach sustainability by encouraging our audience to accept its importance and to adjust their view of the world, taking it into account. We could argue that the concept of sustainability is so important that we should not only learn from it, but also teach it to all ages (Bratucu et al., 2020). Especially in the context of organized education. If we achieve this, then sustainability will be able to contribute the most, both through it and by its acceptance by society.

The concept of sustainable development, which is proposed as a panacea for many of the most pressing environmental, economic and social problems, reflects the ambiguous relationship of these problems to scientific knowledge (Al-Emran & Griffy-Brown, 2023). And by extension to the knowledge produced and transmitted through educators. On the one hand, science is used to legitimize "green development" and on the other hand, it is seen as responsible for many of the current environmental, social and economic problems (Klett & Wang, 2014). Local or traditional knowledge is often proposed as a superior form of knowledge, as it lies outside of science and is seen as representing a closer relationship with "nature" (Murdoch & Clark, 1994). However, local knowledge, like scientific knowledge, can be revised, given the virtue it simply lacks.

Sustainable education contributes to social well-being. It allows students to develop their critical, creative and responsible thinking, which is essential to address contemporary global challenges. Such challenges include environmental degradation, inequality and technological dependence.

Highlighting the role of sustainability in knowledge, as well as in its management in educational ecosystems. Linking tacit and explicit knowledge with innovation, the integration of technology and long-term educational effectiveness.

However, despite the increasing attention to educational sustainability, as viability is also called, there is still a lack of structured approaches. Approaches that would explain how

sustainable knowledge can be created, maintained and transferred within educational organizations. The present study addresses this gap by analyzing the dimensions of knowledge, its impact on educational practice, and its role in building sustainable learning environments.

LITERATURE REVIEW

The Two Dimensions of Knowledge Creation

The basic framework of creative knowledge includes two dimensions: epistemological and ontological (Nonaka, 1998). According to the ontological dimension, knowledge is created only by individuals. The organization is not able to create knowledge without them. The organization and in particular the educational organization (e.g. school, university, research institute) supports creative individuals or provides them with the appropriate framework for knowledge creation. Therefore, the creation of organizational knowledge should be understood as a process that enhances, "organizationally" the knowledge created by individuals and crystallizes it as part of the organization's knowledge network. This process takes place within an expanding "community of interaction", which transcends intra- and inter-organizational levels and boundaries, as is the case in networks of collaboration between schools, universities and research laboratories (Nonaka, 1998).

In contrast to the previous dimension, Michael Polanyi, in 1966, distinguished epistemological knowledge into tacit and explicit knowledge (Polanyi, 1966). The former is personal, related to a specific context and therefore difficult to formalize and communicate. In the educational context of the natural sciences and economics, tacit knowledge is cultivated through laboratory teaching, experimentation, problem solving and educational robotics. On the other hand, explicit or "codified" knowledge refers to that which can be transmitted in formal, systematic language. Such as, for example, mathematical models, physical laws, algorithms and economic theories. Polanyi claims that human beings create knowledge through their interaction with objects, that is, through personal involvement and commitment or through what he calls "embodiment" (Nonaka, 1998; Polanyi, 1966). To know something means to create its image or shape, implicitly incorporating its individual elements. Therefore, scientific objectivity is not the only source of knowledge.

While Polanyi places the study of the content of tacit knowledge in a philosophical context, it is also possible to extend his idea in a more practical direction (Polanyi, 1966). Tacit knowledge contains cognitive and technical elements. Cognitive elements focus on what Johnson-Laird (1983) calls “mental models,” where human beings create models of the world by creating analogies and processing them in their minds (Johnson-Laird, 2010; Nonaka, 1998). Mental models such as schemas, perspectives, paradigms, opinions and beliefs help the individual to perceive and define the world around him (Johnson-Laird, 2010). On the other hand, the technical element of tacit knowledge includes specific know-how, techniques and skills. Note that the cognitive elements of tacit knowledge refer to an individual’s images of reality and their visions of the future, that is, “what is” and “what should be”. The formulation of tacit mental models, through a process of “mobilization”, is a key factor in the creation of new knowledge.

For example, knowledge through experience tends to be tacit, bodily, and subjective, while rational knowledge tends to be explicit, metaphysical, and objective. Tacit knowledge is created “here and now” in a concrete, practical context and involves what Bateson, in 1973, called an “analogous” quality (Leeds-Hurwitz, 2016). Individuals acquire a shared tacit knowledge through communication, and this was an analogical process that required a kind of “simultaneous processing” of the complexity of the common problems they face. Tacit knowledge, derived from experience, is intensely personal knowledge that is difficult to codify.

On the other hand, explicit knowledge concerns events or objects of the past "there and then" and aims at a theory that is independent of context. It is created sequentially, through an activity that Bateson calls "digital" activity. That is, explicit knowledge is knowledge that can be codified and recorded in the form of rules and instructions.

Figure 1 presents the dimensions of knowledge with sustainable knowledge.

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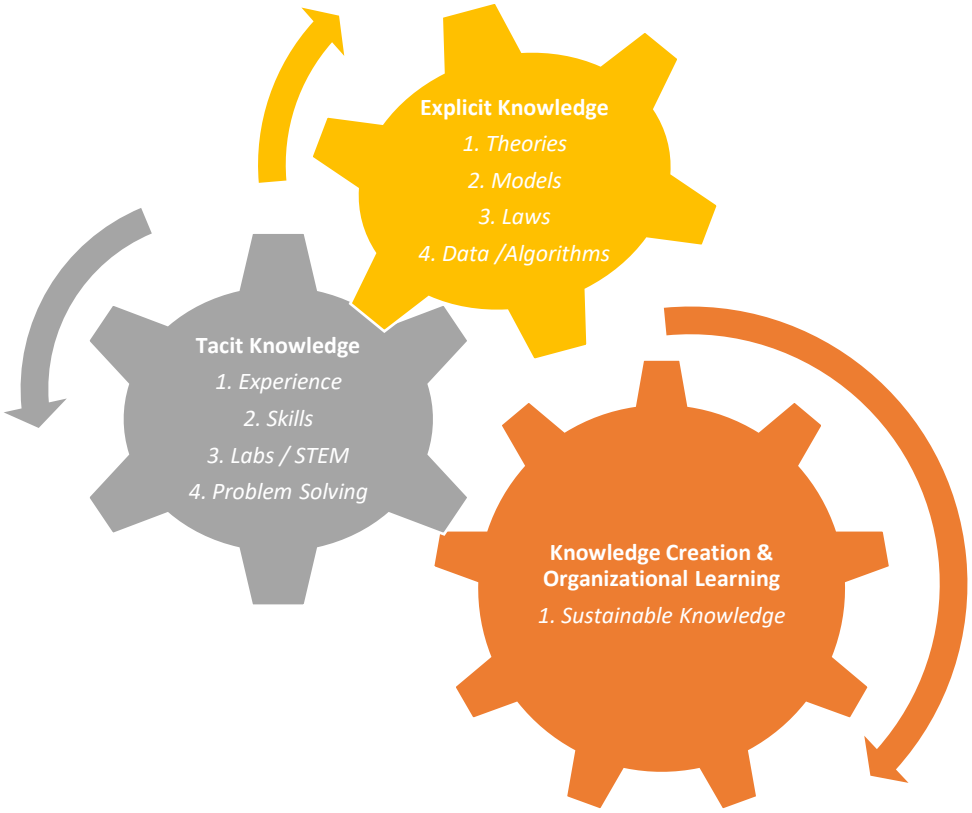

Figure 1. Dimensions of Knowledge & Sustainable Knowledge

Sustainable Knowledge

Over the last decade, there has appeared to be a scientific consensus on the importance of sustainability, both at the organizational, national and global levels. In this context, educational organizations, and especially those active in STEM (Science, Technology, Engineering, Mathematics) and Economic sciences education, are not only expected to be sustainable, but it is also in their interest to invest in sustainability. At the heart of this evolution is knowledge.

Today, society is experiencing a new era where the proper capitalization of knowledge determines competitiveness and long-term sustainability (Zbuchea et al., 2019). As a clear indication of this trend, knowledge management has emerged as a key interest for both academia and practice, immersed in various sectors and disciplines. What was once considered a trendy approach, in today's phenomena has quickly turned into a multi-layered reality: At both the macroeconomic and microeconomic levels, the imperative for knowledge-based processes is becoming timely and compelling (Djeflat, 2010).

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At the macroeconomic level, more and more economic development strategies are based on knowledge, thus demonstrating the tendency of decision-makers to collect, store, create and exploit both existing and new sources of knowledge (Zbuchea et al., 2019). Figure 2 illustrates the flow from education and knowledge, through innovation, to sustainable development. The development of new knowledge, as well as the building of the capacity to access it in specific environments, have emerged as drivers of sustainable development. Organically linked to this development, at a very small level, a wide range of organizations are supporting strategies and practices that lead to effective knowledge management systems, thus recognizing their impact on business performance and indirectly on sustainable development (Djeflat, 2010).

Figure 2. The flow from education and knowledge, through innovation, towards sustainable development.

Supported by these perspectives, new economic and business models give way to a thorough strengthening of the capacity of societies, communities, companies and individuals to use it wisely and benefit from this knowledge. Even more, they place knowledge at the core of their existence and survival, treating it simultaneously as a strategic resource or as a key business asset (Zbuchea et al., 2019).

Nevertheless, the attention paid to public organizations, educational institutions and non-profit organizations allows the examination of a complex frame of reference focusing on internal processes related to knowledge management, as well as intellectual capital. Therefore, more attention needs to be paid to inter-organizational processes, including open knowledge transfers within a specific sector or between different sectors, with the aim of sustainable and inclusive development.

Knowledge retention is a key aspect for educational institutions, as knowledge is one of the most valuable assets. However, to be effective, practical knowledge management must be based on a sound set of principles, which leads to increased innovation capabilities (Zbuchea et al., 2019). Therefore, in educational organizations, the effectiveness of the overall activity is mediated by knowledge management strategies through enhanced innovation. However, knowledge management is part of the strategic equation. In a high-tech and robotic environment, it complements leadership and strategic management in business performance.

Knowledge transfer in the education sector, among others, facilitates innovation to a great extent. Furthermore, collaboration between educational institutions in the value chain is crucial for knowledge creation and innovation (Zbuchea et al., 2019). Therefore, knowledge exchange, collaboration and knowledge preservation should coexist in a balanced manner.

Knowledge sharing is a complex phenomenon (Zbuchea et al., 2019). Knowledge can be an added value for an educational institution, as well as a valuable resource that contributes to organizational development. Therefore, knowledge transfer is a delicate issue. Furthermore, knowledge exchange is related to the absorption and integration of knowledge. Understanding knowledge exchange facilitates the increase of the transferred intensity (Zbuchea et al., 2019).

Knowledge sharing is influenced by many factors which can be grouped into the following dimensions:

- Human factors.
- Organizational characteristics.
- Environment (Zbuchea et al., 2019).

Human factors are associated with individuals involved in the sharing processes, such as the individual's motivation, trust, personality, technological literacy, attitude and peer influence.

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Organizational factors are associated with the characteristics and internal strength of the organization, such as structure, technological and robotic infrastructure, reward and recognition systems, work processes, leadership and organizational relations of cultural and social interaction. Finally, environmental factors concern the economic situation, competing cultures and public policies (Zbuchea et al., 2019).

The following Table 1 summarizes the factors that affect knowledge exchange:

Table 1: Factors Influencing Knowledge Transfer

Factor	Description	Effect on Knowledge	Example
Human	Motivation, trust, skills	Facilitates / Blocks	Collaboration culture
Organizational	Structure, technology (ICT), leadership	Accelerates knowledge flow	Digital platforms
Environmental	Economy, politics, competition	External pressure	Education policy

Knowledge transfers have been investigated by researchers in all types of educational organizations, both for-profit and non-profit. Some of the elements that can be observed when mapping knowledge transfers are the value creation in the chain, the actors and partners, the barriers and tensions.

Facilitating and identifying knowledge sharing is also easy to accomplish, as it can involve a range of processes and support (Zbuchea et al., 2019). In this context, knowledge exchange can be facilitated by social interaction between actors, although it is more difficult to observe. During this process, emotional, intellectual and tacit knowledge can also be transferred, both within the organization and between organizational partners. These processes are sometimes facilitated by strategic alliances, which provide organizations with a competitive advantage. At the core of these alliances is the transfer of knowledge between members. Innovative capabilities depend on both the knowledge and the intellectual capital of educational and research organizations (Zbuchea et al., 2019). By sharing knowledge, educational institutions contribute to increasing their intellectual capital and creating a dynamic advantage over their competitors. This is a valuable advantage of any organization, let alone educational organizations, where it acquires dominant importance.

Nowadays, sustainable development is of increasing concern to the world community,

especially since the Rio Summit in 1992, as major challenges were placed on the international agenda in view of the worsening indicators of increased resource use and worsening environmental impacts (Antrim, 2019). The 1987 Brundtland Report of the World Commission on Environment and Development (WCED, 1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Gro Harlem Brundtland, 1987; McChesney, 1991).

Although many of the tasks and resolutions focus on cost and pricing, both in terms of understanding and policy instruments, issues of science and technological – robotic capabilities have been re-emerging in recent years. It is gradually recognized that sustainability increasingly relies on innovation capabilities and the exploitation of the necessary knowledge (Djeflat, 2010).

In less developed countries, the situation is much more difficult: while GDP growth of 6% to 8% per year is necessary to meet all their needs for the next three or four decades, they must also comply with sustainability requirements, while developing the necessary data and appropriate knowledge, which they often lack (Djeflat, 2010; Stoumpos & Stoumpou, 2025). The transition to a global, networked knowledge economy will be one of the most significant social and economic changes of the coming decades.

Knowledge is known, but in some cases, it is difficult to access and its price is distorted by the global market, based on intellectual property rights and other restrictive practices that do not benefit the least developing countries (Djeflat, 2010).

The sustainability of development is fundamentally based on the ability to properly utilize knowledge (Djeflat, 2010). In other words, "sustainable knowledge" remains of primary importance for sustainable development. This raises important theoretical and conceptual issues regarding the links between sustainability, development and knowledge.

There is a growing belief that Natural Science, Technology and Knowledge play an important role in sustainable development (Djeflat, 2010). Consequently, knowledge systems and the knowledge economy seem to open up new and diverse avenues for exploration towards sustainability.

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In an organized economy, the reuse of resources and the quality of information, growth and efficiency no longer depend on wages and large-scale production. The critical resources are practical knowledge, local business dynamism and trust, collaboration between organizations, human intelligence and know-how (Djeflat, 2010). This contributes to a "human intelligence economy". According to the International Council for Science, in 2002, knowledge can make a substantial contribution to sustainability across a wide range of countries and problems (Report from the ICSU Study Group on Science and Traditional Knowledge, 2002). However, the French National Research Council, in 1999, notes that unless this contribution can be dramatically increased, it seems unlikely that the transition to sustainability will be either rapid or far-reaching enough to avoid significant degradation of human life and the earth system (Constitutional Council, 1999). To achieve this level of contribution, several conditions must be met. These include:

- the specific nature of the knowledge,
- the successful combination of materials and knowledge, and
- the type of knowledge system (Djeflat, 2010).

First, regarding the specific nature of knowledge, on the one hand it obeys public goods rational and evolutionary principles and on the other hand the market rules of a neoclassical framework (Djeflat, 2010). Integrating knowledge and sustainability often requires a mix of the two in a realistic way. It is clear that sustainability is easy when knowledge is public, non-competitive, codified and a source of high externalities. It can thus circulate and be shared more easily between different actors. Its potential for sustainability is reduced if it is proprietary, subject to market rules and intense competition, high protection, silence, specialization and under the constant threat of obsolescence (Djeflat, 2010).

Second, as a result of the ever-increasing proportion of knowledge in the production of goods and services, more and more emphasis is being placed on knowledge assets as a source of wealth creation (Djeflat, 2010). However, these types of assets may not be easily perceived when it comes to sustainability. Several studies reveal that sustainability can be achieved more easily when physical assets are effectively combined with knowledge assets (Djeflat, 2010). Industrial ecology, for example, has already explored ways to effectively combine materials and knowledge. Knowledge management is one of the key elements of this process.

Third, it is becoming increasingly evident that sustainability depends on the development of

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integrated knowledge systems (Djeflat, 2010). This was an essential lesson, widely used in the fields of agriculture, defence and health. The knowledge system approach seems to offer greater insight into the effectiveness of the use of Research and Technology, with the objectives of sustainable development. A knowledge system is considered to consist of a network of connected actors, interested organizations and objects that perform a series of knowledge-related functions (including research, innovation, development, demonstration and adoption) that link knowledge and expertise to action (Djeflat, 2010). Also included are the incentives, financial resources, institutions, and human capital that give such a system the ability to do its job (Djeflat, 2010).

Finally, the importance of intangible assets in sustainability is increasing. While production and development are focused on material, sustainability seems to depend more on intangible assets used to exploit material resources. Therefore, a development strategy that focuses only on productive capital and neglects intellectual capital is not sustainable (Djeflat, 2010). However, society lacks the critical capacity to assess what types of programs, institutional arrangements and general knowledge systems can contribute most effectively to the utilization of Research and Technology to achieve sustainability (Djeflat, 2010).

The example of the knowledge system is usually put in the context of the knowledge economy, where knowledge is considered the basic resource for economic activity and its production and exploitation significantly contribute to wealth creation (Organisation for Economic Co-operation and Development (OECD), n.d.). The knowledge economy framework uses a four-pillar systemic approach:

- Innovation.
  Education.
- Information & Communications Technology (ICT).
- Institutional framework

which shows how knowledge is created, circulated, evaluated and governed for the purposes of economic growth and development (Djeflat, 2010).

Figure 3 presents a visual representation of the four pillars that support the knowledge economy.

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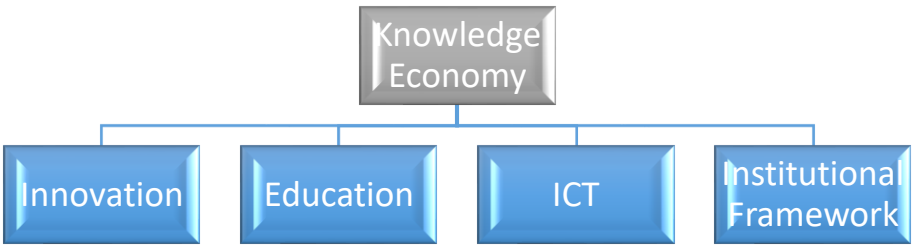

Figure 3. Pillars of Knowledge Economy

The knowledge economy paradigm suggests that natural resources can be extended almost indefinitely through the "substitution" of natural resources by information, knowledge and other resources, thus giving new perspectives on sustainability. By examining each of the components carefully, it is observed that each of them provides a deeper insight into this relationship.

Firstly, Information and Communication Technologies have brought enormous potential for sustainability and environmental protection and have contributed greatly to knowledge (learning, collection and storage of databases, dissemination of vital information, data generation systems, environmental monitoring and control, etc.) (Djeflat, 2010). Recent studies demonstrate the potential of Information and Communication Technologies for sustainability (Stoumpos et al., 2024).

Second, innovation is the key element of sustainability. In an attempt to highlight the key elements of sustainability, many scholars have focused on cost and benefit, which are the two key elements in decision-making for environmental protection. However, this cost-benefit approach does not incorporate the factor of technology. From an empirical point of view, studies conducted in the mining sector have shown that environmental degradation is greater in organizations that work with outdated technology. Due to their mismanagement and their ability to innovate, organizations become more harmful to their environment. Examples throughout the literature show that innovation can reduce pollution and that organizations that adopt this strategy create competitive advantages and environmental benefits. However, pollution control and environmental protection, from the perspective of educational services, are only one of the goals of sustainable development. Sustainability concerns, in addition to health and poverty reduction, education, environmental pollution, prosperity and rural development. Finally, innovation requires the transfer of innovative

capabilities to future generations, in addition to the fact that some results of basic research can be stored to meet future needs (Djeflat, 2010).

Third, education and training should be highlighted when addressing the issue of sustainable development, due to their importance for the production of appropriate knowledge, but also for its dissemination and renewal. As stated in the World Summit on Sustainable Development, young adults tend to emerge from the education system without a deep sense of ecological issues and without knowing how to properly utilize their knowledge. In addition, they are not ready to make environmentally enlightened decisions when they take up positions in the workforce (Rukato, 2002). Therefore, the educational model should promote different values and behaviors, such as cooperation instead of competition. Such an educational approach will be participatory, interactive, integrated, value-oriented and knowledge-based, in the sense of encouraging creativity, innovative attitudes and a continuous effort to renew the stock of knowledge (Djeflat, 2010). Knowledge is under constant threat of becoming obsolete and requires constant learning through academic circles and interactive lifelong learning (Djeflat, 2010).

Finally, one of the key questions is how institutions can play the appropriate role and provide the necessary atmosphere to mobilize knowledge for sustainable development and growth . This raises another issue related to the involvement of the private sector, both as a user and as a source of relevant knowledge for sustainability. It also includes all the other issues typically addressed by the public economy of freedom, the prisoners' dilemma, the alignment of incentives and the distribution of power applied to knowledge (Djeflat, 2010). The policy generally aims to integrate sustainable development as a guiding principle in all government actions in order to ensure that economic and social development remains within ecological limits, especially in the area of Research & Technology policy, where there are no incentives to set strong priorities to promote sustainable development (Djeflat, 2010).

Sustainable Knowledge Management

Successful management of innovation and robotic technology requires effective management of sustainable knowledge acquired from learning processes. This management includes the tools for developing and storing information (Mahmood et al., 2013). In the

educational environment, these systems include digital learning platforms, STEM labs, educational robotics infrastructures, and learning data analytics systems (Stoumpos et al., 2025). Knowledge management means not only maintaining existing knowledge but also developing new knowledge. If learning is the accumulation and dissemination of information, sustainable knowledge management is the preservation and creation of intelligent information systems – systems that can collect data and provide excellent quality information to decision makers (intelligence systems).

Knowledge management, as with organizational learning, depends on the interaction of individuals within the academic institution. These individuals are the agents of action in the information system. They participate in various online knowledge exchange relationships and contribute to the creation of multiple perceptions and opinions. In this way, the decision-making process is improved, as the organization is enriched with new and different knowledge. The knowledge base, which is the subject of management, is created by the abilities of individuals based on experiences, education, available information and intuition (Mahmood et al., 2013).

Knowledge management is considered to be the set of processes that gather data, information and individual learning in a combined manner. This is achieved by identifying, processing and developing the innovative and creative abilities of employees both at an individual and collective level. This management should be done in a systematic way, so that there is a combination of technological infrastructure and the organization, in order for its intellectual assets to create value and exploit it multiply. The first step in developing such a system is to understand how knowledge is created in an educational organization.

The following Table 2 presents a comparison of activities and topics by educational level in three main areas: Natural Sciences, Economics and Robotics / ICT (Information and Communications Technology).

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Table 2. Educational Applications by Level

Educational Level	Natural Sciences	Economic Sciences	Technological Sciences (Robotics / ICT)
Secondary	Experiments, STEM	Financial literacy	Educational robotics
Tertiary	Research, Models	Data analysis	AI, Automation

In secondary education, students engage in experiments and STEM in science, learn financial literacy in economics, and are introduced to educational robotics, gaining basic skills and practical experience. In higher education, the approach becomes more advanced and analytical, with an emphasis on research and models in science, data analysis in economics, and the application of AI (Artificial Intelligence) and automation in robotics and Information Technology (IT). Overall, the Table 2 shows a clear progression from practical, introductory activities to more theoretical and technologically advanced applications. However, always maintaining the connection to the respective field and highlighting the evolution of learning by educational level.

The Role of Knowledge in Sustainable Innovation

Since innovations are not a purely technological project, the knowledge required for their successful management cannot be covered by natural science and engineering alone (Stoumpos & Talias, 2021). Sustainable innovations can be subdivided into two areas:

- In technical knowledge and knowledge transfer (Bohn, 1998) and
- In learning concerning the administrative methods offered for the management of technology (Rasmussen, 2017).

In order to enhance the systematic development of sustainable innovations, an educational or research organization needs to have access to two types of knowledge, namely technical and managerial knowledge.

However, to concern the entire educational organization and not individual persons, learning and knowledge should be accessible to all individuals, who should be able to use, apply, modify and adopt them. However, for learning to be real and not be reduced to “simple adaptation”, it should be generalized. That is, from simple copying to application, change

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and improvement. In addition, it should include “learning rules”, change and adapt them and not parrot previous successful methods. Finally, in the case that learning includes innovations, it should also consist of a management system for the present and the future.

Successful innovation management can benefit from a systematic approach to knowledge management. Knowledge, learning and the framework for their development are classic definitions that are being redefined in the context of the advancement of information technology and knowledge management. Knowledge management can be seen as a socio-technical system of implicit and explicit business policies and practices. These practices and policies are facilitated through the strategic integration of information technology tools, business processes as well as intellectual, human and social capital. The ability of people and the organization to think rationally, learn, express themselves and envision themselves collectively or individually can be considered as managerial, sustainable and cognitive.

Organizational memory, intelligence and mindset are important and determining factors of cognitive processes both at the individual level and at the level of an educational organization (Rasmussen, 2017).

Figure 4 shows the flow from knowledge management and innovation to organizational performance and sustainable competitive advantage.

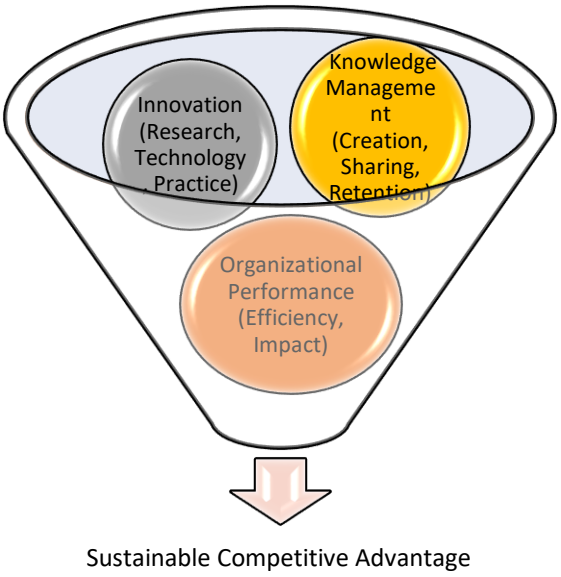

Figure 4. Sustainable Competitive Advantage

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METHODOLOGY

This study follows a qualitative research approach, based on narrative literature review and conceptual analysis. The purpose of the methodology is to systematically investigate and synthesize existing scientific knowledge on the sustainability of knowledge, knowledge management, innovation and the role of education in the natural sciences, economics and technology.

The collection of material was based on international scientific literature (articles, books and reports of international organizations), with an emphasis on fundamental theoretical approaches, such as the distinction of knowledge into explicit and implicit (Nonaka, 1998; Polanyi, 1966), mental models (Johnson-Laird, 2010), as well as on contemporary studies that link knowledge with sustainable development and organizational management (Djeflat, 2010; Zbuchea et al., 2019). At the same time, sources related to technological development, innovation and education policies were utilized (OECD, 2013, 2019, 2021; Organisation for Economic Co-operation and Development (OECD), n.d.), in order to form a comprehensive theoretical framework.

The data analysis was carried out through thematic grouping of the main concepts and axes emerging from the literature. Specifically, the following were identified and examined: (a) the dimensions of knowledge (explicit and tacit), (b) the mechanisms for managing and transferring knowledge in educational institutions, (c) the factors that influence the sustainability of knowledge (human, organizational and environmental), and (d) the connection between knowledge, innovation and sustainable development.

Through conceptual synthesis, the study is led to the formulation of interpretative conclusions regarding the role of sustainable knowledge in the formation of modern educational organizations. This specific methodological approach allows for an in-depth understanding of complex theoretical concepts and the highlighting of relationships between knowledge, education, technology and sustainability, without the need for empirical collection of primary data.

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RESULTS

The findings of the study demonstrate that sustainable knowledge is a building block for the development of modern educational organizations. Its impact is direct on the creation of innovation, the cultivation of skills and the formation of a resilient educational ecosystem (Djeflat, 2010; Zbuchea et al., 2019). First, it is shown that the two dimensions of knowledge, both explicit and tacit, coexist and function complementary in the learning process. On the one hand, explicit knowledge allows for the systematic codification, transmission and standardization of educational content, while on the other hand, tacit knowledge is linked to experiential learning, creativity and the development of critical and analytical thinking, elements that are fundamental to the sustainability of knowledge (Johnson-Laird, 2010; Nonaka, 1998; Polanyi, 1966).

Secondly, the results indicate that effective knowledge management in educational institutions is linked to the preservation and utilization of intellectual capital, collaboration, knowledge exchange and the development of digital infrastructure (Hosseinzadeh et al., 2020; Mahmood et al., 2013; Zbuchea et al., 2019). The existence of appropriate technological equipment, information systems and educational robotics acts as a lever to enhance innovation, as well as to support sustainable educational development (Al-Emran & Griffy-Brown, 2023).

Thirdly, it is found that the knowledge environment, the economic framework, the institutional structures and the educational policies, decisively influence the transfer, exchange and sustainability of knowledge. Educational institutions that operate within favorable environments of policies, technological development and support for innovation show a greater ability to produce new knowledge and enhance their competitiveness (OECD, 2013, 2019, 2021; Organisation for Economic Co-operation and Development (OECD), n.d.).

Finally, it emerges that the connection of education with technology, innovation and knowledge leads to the development of a sustainable competitive advantage for educational institutions and contributes to the creation of competent, creative and socially responsible citizens. The concept of “sustainable knowledge” appears as a crucial factor for the

formation of educational organizations, which can respond to modern social and technological challenges (Djeflat, 2010; Murdoch & Clark, 1994; Sharkie, 2003).

DISCUSSION

The findings of the study indicate that sustainable knowledge is a central axis not only for enhancing educational effectiveness, but also for innovation and social development. The finding that explicit and tacit knowledge work complementary strengthens the international bibliography. According to which, the creation and maintenance of knowledge is not limited to theoretical transfer, but is linked to experiential experiences, practical training, collaboration and active participation of learners. The importance of tacit knowledge, especially in the fields of Natural Sciences, Technology and Economics, confirms that learning must be based on practical activities, experimentation and development of high-level skills.

At the same time, the recognition of the role of knowledge management in educational institutions confirms that universities and school units now operate as knowledge organizations. Where information, human resources and technology are strategic resources. The use of technological tools, educational robotics, digital learning platforms and education data analysis systems enhances knowledge, reduces the risk of intellectual capital loss and supports long-term sustainable development.

At the same time, the relationship between knowledge, innovation and sustainable development suggests that education is a critical factor in the transition to a knowledge society. Educational institutions that invest in knowledge and technological development create conditions for economic progress, social well-being and enhanced competitiveness. However, the success of these efforts depends largely on education policies, the existence of institutional support, economic stability and the cultivation of a culture of cooperation and knowledge exchange.

Finally, the results highlight that sustainable knowledge is not only an academic concept, but a practical tool for strategic development. Educational institutions that manage to create, maintain and exploit knowledge gain a sustainable competitive advantage. At the same time,

contributing to the formation of citizens capable of meeting the demands of modern society and supporting a model of sustainable development.

CONCLUSIONS

In the context of secondary and tertiary education in the natural sciences and economics, sustainable knowledge is a key factor in creating creative, innovative and socially responsible graduates.

In summary, educational institutions operate in all sectors through people, whose contribution determines their success. The skills and knowledge of the staff must be cultivated and properly utilized in order to create a competitive advantage. The sustainability of this competitive advantage comes from the development of closely coordinated and complementary activities, directed towards the production of a strategic differentiation. Therefore, the development of a sustainable competitive advantage is vital for the operational management of an educational organization. This is because it is an important requirement for the cultivation of a creative knowledge environment. Which allows the exploitation and development of resources and contributes to the creation of sufficient knowledge repositories to address the future factors of an educational organization (Sharkie, 2003).

The success of an academic institution depends on the speed with which it can create, capture and disseminate knowledge and then use it to develop skills that are difficult to replicate. The ability to create and continuously search for knowledge can give an educational organization a competitive advantage, as the innovative knowledge developed today will become the basic knowledge of tomorrow (Sharkie, 2003). To this end, the issue of sustainable knowledge and sustainable competitive advantage is very important.

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