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Formation of a Paradigm for Designing Cyber-Physical Systems: Educational Perspective

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ABSTRACT

The subject of the article is the process of forming a paradigm for designing cyber-physical systems. The object of the work is cyber-physical systems. the purpose of the work is to increase the efficiency of cyber-physical systems in the economy and society. To achieve this goal, the following tasks are solved: the formation of a paradigm for designing cyber-physical systems. descriptions of methodological provisions of the general theory of cyber-physical systems. descriptions of the factors generated by the general theory of cyber-physical systems to increase the effectiveness of such systems. General characteristics of methods of design and research of cyber-physical systems at all stages of their life cycle. description of the content of new academic disciplines in the field of design and research of cyber-physical systems. Methods of the article are philosophy and methodology of science, theory of hierarchical systems, theory modeling, historical and system analysis, and theory of technological structures. The scientific novelty of the article is associated with the formation of the design paradigm of cyber-physical systems and the creation of a general theory of cyber-physical systems.

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1. INTRODUCTION

The relevance of the article is determined by the need to develop scientific support for the design of cyber-physical systems in the conditions of the formation of a new technological order.

To increase the efficiency of cyber-physical systems of a new generation, it is necessary to form effective scientific support for the development, research, and operation of cyber-physical systems. At the same time, the development of various types of cyber-physical systems by 2023 can be considered one of the key directions of the formation of a new 10th technological order.

The hypothesis of the article is the statement that to increase the efficiency of cyber-physical systems and their design processes, it is necessary to develop a general theory of cyber-physical systems and a paradigm of their system design.

The work aims to increase the efficiency of cyber-physical systems in the economy and society. To achieve this goal, the following tasks are solved:

(i) formation of a paradigm for designing cyber-physical systems;
(ii) descriptions of methodological provisions of the general theory of cyber-physical systems;
(iii) descriptions of the factors generated by the general theory of cyber-physical systems to increase the efficiency of such systems;
(iv) general characteristics of methods of design and research of cyber-physical systems at all stages of their life cycle;
(v) description of the content of new academic disciplines in the field of design and research of cyber-physical systems.

The object of the work is cyber-physical systems in the period of the 10th technological order. The subject of the article is the paradigm of designing cyber-physical systems. An analysis of the published research results on the topic of this article shows the following. The design and analysis of cyber-physical systems are considered priority scientific and practical tasks at the beginning of the 21st century (Solihat & Pratami, 2021). The countries of the European Union formulate their strategy in the field of development of cyber-technical systems (Nurdini & Hadianto, 2018; Magayanes, 2022). Scientists believe that the development of automated enterprise management systems is an important task in automating production processes in 2023 (Zykin & Kataeva, 2018). Analysts believe that the formation of the theory of technological orders creates a unique opportunity for the modernization of production facilities during their transition to a new 10th technological structure (Glushchenko, 2023a). The researchers predict that the main trend in the development of a new technological order will be the synthesis and introduction into practice of many new technologies: nanotechnologies, information technologies, digitalization technologies, neurotechnologies, and others (Glushchenko, 2021a). Scientists believe that computer-aided design systems for products and technological processes will be developed within the framework of the new technological order (Glushchenko, 2023a).

Teachers believe that it is necessary to develop intellectual educational and research CAD systems (Kataev *et al.,* 2013). The researchers note that when designing computer-aided design (CAD) systems, erroneous design decisions are possible (Al Husaeni & Nandiyanto, 2022). Scientists believe that at the beginning of the 21st century, it is necessary to develop the theory of scientific activity, to modernize scientific and innovative activities (Husnah *et al.,* 2021). Analysts believe that one of the directions of modernization of innovation activity may be the creation of technology platforms (Gustap, 2012). The researchers believe that in

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the conditions of the new technological order, the methods of ergonomic design will be actively used in practice (Glushchenko, 2022a). Due to the intensification of innovative activity, enterprises will increasingly use the project (rather than process) model of organizations' activities (Glushchenko, 2022b). Scientists express the point of view that the effectiveness of innovative activity through the development of methods for the synthesis of effective innovative ideas (Glushchenko, 2021b). Experts consider design thinking to be a way to increase the effectiveness of innovative projects (Glushchenko, 2023b). Analysts express the point of view that the methods of ergonomic design can be used to improve the efficiency of scientific support for CAD. Teachers note the development of clip and lateral thinking in students, which can affect the effectiveness of their work in the real economy (Shah, 2022). The analysis of scientific publications on the topic of this article allows us to draw the following conclusions: cyber-physical systems will be one of the main directions of technical development during the new technological order; the concept of a cyber-physical system is controversial; the general theory of cyber-physical systems has not yet been developed; the paradigm of designing cyber-physical systems has not yet been developed. This confirms the relevance of the topic of this article.

2. METHODS

This study is a literature survey. This study took data from an internet source, especially from articles published in international journals.

3. RESULTS AND DISCUSSION

At the beginning of the 21st century, cyber-physical systems (Eng. cyber-physical systems) act as one of the key areas of technology development in the new technological order. Cyber-physical systems can be considered a qualitatively new stage in the development of automation of production facilities and manufactured products. Historically, this development of automation tools was given a great impetus by the creation of computers and automation tools during the 8th technological order in 1940-1970 (Glushchenko, 2023a). Currently, the essence of cyber-physical systems has not yet been thoroughly investigated. For this reason, there is no general theory of cyber-physical systems. In turn, the absence of a general theory of cyber-physical systems can lead to methodological errors in the design of such systems (Al Husaeni & Nandiyanto, 2022).

In 2023, cyber-physical systems are understood as a wide class of systems with such properties:

(i) A cyber-physical system is a system combination of such structural elements: information technologies, artificial intelligence, computing facilities, and physical devices; digitalization technologies; databases.

(ii) Such a system is characterized by a distributed type of control process in a cyber-physical system.

(iii) The basis of the control part of such a system is intelligent control technologies.

(iv) Physical elements in such a system can act as the supporting structure of this cyber-physical system (for example, the body of an unmanned vehicle); external information sensors (air pressure receivers, gyroscopes, etc.); transmitting devices (conveyors, gearboxes, etc.), mechanical drives of various types (hydraulic, pneumatic, etc.), actuators (for example, a mechanical "arm" of a robot) and other things.

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(v) Computing facilities (most often having the form of microprocessors) are distributed throughout the structure of such a system, so the computing subsystem has at least a two-level form.

(vi) The cyber-physical system has a hierarchical character, which implies the presence of such a system of several hierarchical levels with their own goals and management tasks.

(vii) In cyber-physical systems, their computational part is systemically connected by its characteristics and algorithms of functioning with the physical elements of this system, which generates a synergetic effect in the process of functioning of cyber-physical systems.

(viii) From the point of view of management theory, all tasks in the management subsystem of a cyber-physical system can be divided into two hierarchical levels (parts): the tasks of the first (lower) level are the tasks of managing technological processes; the tasks of the second (upper) level are the tasks of managing methods for solving technological management problems.

(ix) The information part of the cyber-physical system includes various kinds of databases, and various systems for obtaining, digitizing, converting, storing, processing, and analyzing data.

(x) Digitalization technologies are an important part of such systems. They provide the conversion of analog signals of the physical part of the cybersystem into a digital code suitable for working with it in the computational part of the cyber-physical system.

(xi) When creating cyber-physical systems, several advanced technologies characteristic of the 10th technological order are used in a complex manner, at the same time, and more.

The methodology of designing cyber-physical systems can be recognized as system engineering. Systems engineering originates from the theory of hierarchical systems. System engineering is a harmonious combination of knowledge from various fields. Such complex knowledge, as a result of their integrated use, makes it possible to solve in practice the problems of designing, manufacturing, handling, and operating real cyber-physical systems.

The analysis of approaches to determining the scope of practical use of cyber-physical systems shows the following. A broad and narrow interpretation of the concept of a cyber-physical system is possible. With a narrow interpretation of the concept of "cyber-physical system", the types of cyber-physical systems can include: industrial robots; unmanned vehicles; autonomous robots; the Internet of things; nanotechnological devices; neurotechnological devices, and more. Prospects for the development of neurotechnologies in the period of a new technological order are described in the work (Glushchenko, 2021c). The criterion for attributing a certain type of product to cybersystems can be considered the presence of such a product or production of all the above 11 signs of cyber technical systems.

With a broad interpretation of the concept of a cyber-physical system, such systems may include systems that: firstly, possess most of the 11 properties listed above; secondly, do not possess some of the 11 properties listed above. With a broad approach, cyber-physical systems should include: computer-aided design (CAD) systems; some types of neurotechnologies; simulators and simulators; big data analytics; cloud computing; quantum computing; augmented reality; virtual reality; metaverse; three-dimensional printing; printed electronics and other.

An integrated approach to the use of knowledge is the basis for increasing the economic efficiency of science in a new technological way. The analysis of publications shows that there are a significant number of publications on the topic of cyber-physical systems in 2022. At the same time, these often have a local character. These publications often do not have further theoretical development. The absence of large centers of theoretical development on this

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topic can be indicated mainly by the isolated nature of the publications of one author or a team of authors. At the same time, there is no information about the implementation and practical effectiveness of specific publications.

In the period of development of a new technological order, a general theory and paradigm for designing cyber-physical systems are required. Such a general theory and paradigm of designing cyber-physical systems should become the basis for increasing the economic efficiency of real cyber-physical systems. In addition, to improve the quality of higher education in this area, it is necessary to introduce new academic disciplines for university students.

Let's agree to call the paradigm of cyber-physical design system integration (aggregation): philosophy, ideology, politics, organizational culture, mission, vision, goals, and objectives of creating such systems. The philosophy of designing cyber-physical systems will be called the most general, wise view of the process and results of designing cyber-physical systems. The formation of the philosophy of designing cyber-physical systems finds its expression in the description of the principles of designing such systems. The principles of designing cyber-physical systems can be called: integrated design of the entire "technological pyramid" of cyber-physical systems; systematic coverage of the entire life cycle of a cyber-physical system; ensuring the efficiency of the design process; minimizing unproductive losses; integrated use of various types of technologies; the principle of managing ways to solve technological problems; the principle of maximizing the use of advanced technologies; the principle of using project team members with taking into account their maximum qualifications and others.

At the same time, the principle of integrated design of the entire "technological pyramid" of cyber-physical systems assumes that the entire "technological pyramid" of such systems should be covered by the design process. Such a "technological pyramid" of cyber-physical systems includes the following hierarchical levels: the highest level of the hierarchy provides conceptual developments and the creation of new technological principles; at the second level of the technological pyramid, technologies for the functioning of cyber-technical systems are synthesized; at the third level of the technological pyramid, these cyber technical systems are designed and manufactured; at the fourth level, these cyber-physical systems are operated in the production process; at the fifth level of this pyramid, firms carry out maintenance and training in the methods of operation of cyber-physical systems.

All five hierarchical levels of the cyber-physical system have their specifics and should be designed within the framework of a systematic approach.

The situation is similar to a systematic approach to the design of all stages of the life cycle of cyber-physical systems. In the simplest case, three stages of the life cycle of a cyber-physical system can be distinguished: production (which includes the design stage); the circulation of a cyber-physical system on the market; the stage of operation of a cyber-physical system by its owner.

At the same time, the elements of the cyber-physical systems design paradigm should systematically cover all levels of the technological pyramid and all stages of the life cycle of the cyber-physical system.

As a result, for example, the philosophy of designing a cyber-physical system should systematically combine (aggregate) 15 elements. These elements are a 5*3 matrix. The elements of this matrix can be synthesized using the "morphological box" methodology known in the practice of scientific and technical forecasting. Each compartment of this morphological box should contain the philosophy of designing a certain part of the "technological pyramid" at a certain stage of its life cycle. For example, the element of this "morphological box" with the number 5:1 should contain the philosophy of either designing

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a cyber-physical system maintenance system or the philosophy of professional training in the methods of using this cyber-physical system at the stage of its operation. At the same time, the element of this morphological box with the number 3*3 should contain the philosophy of exploitation of this cyber-physical system by its owner, etc.

At the same time, this "morphological box" sets the structure of the graph tree of the philosophy of designing such systems. The same procedure of philosophy decomposition can be applied to the formation of philosophies from lower-level elements.

A similar procedure can be used in the decomposition of the ideology of designing cyber-physical systems. The ideology of designing cyber-physical systems can be understood as: firstly, the key idea of creating a cyber-physical system (or its elements); secondly, the way power is distributed among the stakeholders of this process.

In addition, this decomposition procedure can be applied to create cyber-physical systems. As a result of using the proposed decomposition procedure, a graph tree of the goals of creating a cyber-physical system can be obtained.

Thus, we can say that in the process of forming a paradigm for designing cyber-physical systems, the proposed design procedure can be applied to the philosophy, ideology, and goals of designing a cyber-physical system.

At the same time, the functional decomposition representation of complex systems can be used for the synthesis and analysis of the functional structure of a cyber-physical system (Glushchenko, 1990).

The design paradigm of cyber-physical systems is closely related to the general theory of such systems. This is explained by the fact that during the development and operation of cyber-physical systems, scientific results from this field of knowledge are introduced.

This creates a need for the development of a general theory of cyber-physical systems. Such a general theory can be the basis for the formation of the structure of a scientific platform to support the processes of designing and operating cyber-physical systems. It should be borne in mind that it is known from the philosophy and methodology of science that only the general theory of cyber-physical systems can be the most developed and practically effective form of scientific knowledge in this scientific field. In this regard, it is necessary to formulate the key methodological provisions of the general theory of cyber-physical systems. As part of this approach, it is necessary to do the following:

(i) describe methodological, instrumental, cognitive, legislative, prognostic, optimization, preventive functions, the function of knowledge socialization, psychological, system-forming function, and risk reduction function;
(ii) formulate the roles of the general theory of cyber-physical systems;
(iii) describe the laws of the general theory of cyber-physical systems;
(iv) methodologically define the concept of the paradigm of development and design of cyber-physical systems and others.

The purpose of this work is to increase the socio-economic efficiency of scientific support of cyber-physical systems in the conditions of transition to a new technological order. To increase the efficiency of the use of scientific knowledge in the field of cyber-physical systems design, it is possible to create a scientific platform for cyber-physical systems using the general theory of such systems.

In the field of the theory of cognition (epistemology), the general theory (science) of cyber-physical systems can act as a complex of methods and methods that allow the classification of facts in the field of design, production, circulation, and functioning of cyber-physical systems; methods that allow the study, analysis, forecasting, diagnostics of cyber-physical

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systems; methods of managing methods for solving research problems cyber-physical systems at all stages of their life cycle and more.

The practical significance of the scientific theory of cyber-physical systems is to increase the effectiveness of the practical use of scientific knowledge in this field. At the same time, there may be a reduction in the risks characteristic of the design and functioning of cyber-physical systems. The scientific theory of the design and functioning of cyber-physical systems will be called: the scientific method, as a set of techniques and principles, with the use of which an objective study of phenomena describing the specifics of a particular cyber-physical system, analysis, diagnostics, design of systems, states, and situations within the framework of the studied cyber-physical system is provided.

The methodological function of the general theory of cyber-physical systems is to form the theoretical basis of this science. The methodological function includes the following: development of the conceptual basis of the theory of cyber-physical systems; synthesis of the methodology of scientific research of the processes of designing and functioning of cyber-physical systems; study of facts, and phenomena observed in the process of designing and operating cyber-physical systems and their components; formulation of categories and laws of the synthesized scientific discipline.

The cognitive function of the complete theory of design and operation of cyber-physical systems combines the following processes: extraction, description, and classification of knowledge in this field; methods of knowledge analysis in the field of cyber-physical systems; evaluation of individual processes and phenomena in the post-industrial conditions of the development of a new technological order.

The regulatory (instrumental) function of the complete theory of cyber-physical systems consists of the development of effective concepts, methods, techniques, and tools for managing the process of implementing the life cycle of cyber-physical systems. This function has a practical focus.

The legislative function of the complete (general) theory of cyber-physical systems consists in the development of legislation that provides: favorable conditions for the scientific development and practical application of cyber-physical systems; motivating participants in the development of the sphere of cyber-physical systems.

The optimization function of the general (complete) theory of cyber-physical systems consists of the following: the formation of indicators and criteria for assessing the socio-economic efficiency of cyber-physical systems; the synthesis of methods of analysis, comparison, and selection based on a certain criterion of the most effective variants of cyber-physical systems; the formation of indicator systems to assess the effectiveness of the components of cyber-physical systems and others.

The prognostic function of the general theory of cyber-physical systems consists in the formation of probabilistic estimates of the characteristics of promising states of cyber-physical systems and/or their constituent parts; predictive analysis of the prospects for the development of the sphere and individual areas of cyber-physical systems.

The preventive function of the general theory of cyber-physical systems is: to study the causes of possible deviations in the development of the sphere of cyber-physical systems or its directions; to develop and implement an action plan aimed at minimizing risks and damages in the development of the sphere of cyber-physical systems as part of a new technological order.

The psychological function of the general theory of cyber-physical systems is to form a sense and perception of the need to develop the sphere of cyber-physical systems as an important socio-economic and technical and technological aspect of economic efficiency

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growth, increasing the security and comfort of society in the process of developing a new technological way.

The function of knowledge socialization in the general theory of cyber-physical systems is as follows: structuring, classification, storage of information; transfer to the social environment of society and the professional environment of information about the meaning and methods of development of cyber-physical systems of their role in the economy and society.

The system-forming (aggregative) function of the general theory of cyber-physical systems consists of the complex use of knowledge in the field of cyber-physical systems. At the same time, the peculiarities of knowledge accumulation, their structuring, classification, and effective practical use should be taken into account.

The roles of the general theory of cyber-physical systems can be recognized as increasing the economic efficiency of the processes of designing and operating cyber-physical systems; reducing the risks of developing the sphere of cyber-physical systems in the process of becoming a new technological order; increasing the efficiency of investments in the development of the sphere of cyber-physical systems. cyber-physical systems and much more.

Under the laws of the development of the sphere of cyber-physical systems, we agree to understand stable cause-and-effect relationships between processes and indicators of the functioning of the sphere of cyber-physical systems as part of a new technological order.

The laws of development and functioning of the sphere of cyber-physical systems can be formulated as follows:

(i) the development of the sphere of cyber-physical systems as a sphere of human activity is associated with the processes of division and specialization of labor; development of science; practical implementation of information technologies;

(ii) the formation of the sphere of cyber-physical systems is the result of the active introduction of information technologies into the design processes of new types of products;

(iii) the development of the sphere of cyber-physical systems is based on distributed control systems;

(iv) any cyber-physical system is a large and complex humanistic system consisting of many parts (subsystems): information sensors; information technologies; actuators; computer technologies and others;

(v) following the specifics of the activity and the level of abstraction of the activity, the sphere of cyber-physical systems within one technological structure is a "technological pyramid of cyber-physical systems". This pyramid includes five hierarchical technological levels: 1) synthesis of new technological principles of cyber-physical systems; 2) development of technologies for the functioning of cyber-physical systems; 3) production of cyber-physical systems as technical objects; 4) the process of functioning of cyber-physical systems in the real economy and society; 5) maintenance and training processes for the use of specific cyber-physical systems;

(vi) the level of economic efficiency of cyber-physical systems is related to the industry affiliation of these systems and the possibilities of multiple uses (animation) of industrial cyber-physical technologies in the processes of creating new models of products and equipment;

(vii) the life cycle of cyber-physical systems includes the stages of emergence, growth, maturity, aging, and modernization within the framework of subsequent technological orders.

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The functions of the general theory of cyber-physical systems can be considered the main directions of the development of the scientific foundations of this theory, which have great cognitive (epistemological) and practical significance.

The key scientific objectives of the development of the general theory of cyber-physical systems can be considered: the development of research methods in the field of cyber-physical systems; the development of the theory of designing cyber-physical systems; system analysis and synthesis of cyber-physical systems as anthropogenic objects.

We will recognize the following tasks as the main practical tasks of the general theory of cyber-physical systems:

(i) goal-setting of the development processes of the entire sphere and industry areas of cyber-physical systems;
(ii) -technological marketing in the field of cyber-physical systems, as a synthesis and selection of optimal technical tools for the development of this type of systems;
(iii) management marketing (search for management tools) for the development of the sphere and industry components of cyber-physical systems;
(iv) management of the processes of formation of new directions and technologies of cyber-physical systems, taking into account the need to ensure balance in the triangle of "people-goals-resources" during the development of this sphere;
(v) forecasting and planning (strategic and current) of the development of the sphere and industry directions of cyber-physical systems and their constituent elements;
(vi) analysis of the appearance and/or processes of formation of cyber-physical systems in the sectors of the economy and the national economy as a whole;
(vii) diagnostics of the processes of development of the sphere of cyber-physical systems, assessment of the level of development of cyber-physical systems as a whole, and/or the development of certain types of cyber-physical systems technologies;
(viii) formation of a system of motivation of participants in the process of development of the sphere of cyber-physical systems, and its branch directions;
(ix) control of the state and processes of development of the sphere of cyber-physical systems and more.

Methods of the complete theory of cyber-physical systems can be considered: design thinking; ergonomics of cyber-physical systems; unification (aggregation) of elements; separation into parts (decomposition); system synthesis and analysis; predictive analysis in cyber-physical systems; formation of typical representations of cyber-physical systems; modeling of cyber-physical systems; heuristic forecasting on the development of cyber-physical systems and others

Research shows that the development of a new technological order will further strengthen the impact of innovation, technology, science, and education on the economy and society (Glushchenko, 2023a).

In the scientific platform of cyber-physical systems, blocks can be distributed according to the following criteria: based on the functions of the theory of cyber-physical systems; by branches of the economy; key technologies of the new technological order, and others. The introduction of new technologies into cyber-physical systems and the economy, in turn, will lead to an increase in the economic efficiency of science and innovation. This will ensure scientific and technological progress in the field of cyber-physical systems. In the process of developing the science of cyber-physical systems (as a scientific platform), it should be taken into account that the functions of the theory of cyber-physical systems can be considered as the directions of its development (Husnah *et al.,* 2021).

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Using the functions of the science of cyber-physical systems as research areas and/or a system-forming factor in the formation of a scientific platform will: improve the coordination of scientific research; reduce the number of insufficiently studied areas in the scientific support of cyber-physical systems; reduce the likelihood of duplication and unsuccessful research.

It is necessary to develop the theory of cyber-physical systems as a single methodological basis for the design, creation, and functioning of this class of systems. The development of the general theory of cyber-physical systems creates a methodological basis for the development of a scientific platform for such systems. In this process, it is recommended to take into account the experience of creating technology platforms in the European Union as a tool for information contacts (Gustap, 2012).

Under the scientific platform in the development of cyber-physical systems, we will agree to understand the systematic unification of scientific knowledge from various branches of science. This scientific platform should include the knowledge necessary to solve the following tasks: design and analysis of cyber-physical systems; evaluation of projects to create cyber-physical systems; research at all stages of the life cycle of cyber-physical systems.

The architecture of the scientific platform of cyber-physical systems will be called a systematic combination of such factors: the style of creating cyber-physical systems; art, emotional perception of the processes of designing cyber-physical systems; a harmonious combination of processes at all stages of the life cycle of cyber-physical systems; harmonization of the processes of interaction of stakeholders in the development of the sphere of cyber-physical systems.

The main tasks of the ergo design of cyber-physical systems and the architecture of the scientific platform of cyber-physical systems can be recognized: the formation of a unified style of obtaining, systematization, evaluation, and practical use of knowledge; optimization of the processes of obtaining and using knowledge at all stages of the life cycle of cyber-physical systems.

In the process of developing cyber-physical systems and platforms for scientific support for the creation of cyber-physical systems, imbalances are possible. If these imbalances occur, they can lead to a decrease in the effectiveness of scientific support for cyber-physical systems. The method of ergonomic design can be considered a tool to reduce the likelihood of imbalances in the scientific support of cyber-physical systems.

The ergonomic design of the scientific platform of cyber-physical systems will be called the method and specifics of the coordination of the structure, the nature of the interaction of various elements of cyber-physical systems, and scientific approaches in this area.

To ensure the effectiveness of the scientific platform of cyber-physical systems, the following factors can be taken into account:

(i) methods of obtaining, storing, and classifying scientific knowledge about cyber-physical systems based on the functions of the general theory of such systems;
(ii) the practical application of knowledge organized in the form of a scientific platform of cyber-physical systems can be more effective. This is because this approach provides an increase in the level of integration of knowledge in the process of their practical application;
(iii) increasing the economic efficiency of the practical application of knowledge about cyber-physical systems within such a scientific platform based on the harmonization of the processes of obtaining, classifying, storing, and using knowledge;

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(iv) the creation of a scientific platform for cyber-physical systems can allow students to increase the level of knowledge acquisition and acquisition of practical skills (competencies).

This study explains the mechanism of ensuring the effectiveness of scientific support for cyber-physical systems based on harmonization and practical integrated use of knowledge in the implementation of an innovative project to create such a system. The analysis of the factors of the effectiveness of the innovation project confirms that the scientific support of cyber-physical systems can affect the economic efficiency of the innovation project. Scientific knowledge helps to solve many problems related to external and internal factors of such an innovative project. The list of factors determining the effectiveness of the project is presented in the work (Husnah *et al.,* 2021). To create a competitive sample of cyber-physical systems on the global market, it is necessary to solve the following external problems of this project on a scientific basis: the search for an acceptable cost, and risk sources of financing for the project; the creation of a pool of venture investors and business angels; the formation of a pool of project underwriters (this is part of the specialty finance and credit); analysis of the specifics and capacity of the target for this type of cyber-physical systems of the market segment; formation of the image of the consumer; determination of the consumer's requirements for the product and more. These external scientific and practical problems of the project of creating a cyber-physical system should be solved in systemic unity with the internal problems of this innovative project. As already noted, the list of typical scientific external and internal problems of a typical innovation project is described in the work (Glushchenko, 2022a). Taking into account the specifics of the cyber-physical systems project, this list should be adapted to the conditions, goals, and objectives of the project to create a specific cyber-physical system. At the same time, it should be borne in mind that these external and/or internal scientific and practical management decisions concerning the cyber-physical system development project may be interrelated.

The development of a general theory and a scientific platform for cyber-physical systems can be even more cost-effective if it is integrated with a more active application of product and project approaches in scientific and/or innovative activities. Within the framework of the project approach, the following can be carried out: the organization of project teams; the formation of matrix organizational structures in project organizations; the development of a productive organizational culture of firms engaged in the development and other types of work in the field of cyber-physical systems at all stages of their life cycle. The project model of the organization's activity is presented in the work (Glushchenko, 2021b).

Increasing the effectiveness of the general theory of cyber-physical systems as a method of increasing the economic effect of the practical use of scientific results can contribute to the active use of modeling of technological processes of extraction and practical use of scientific knowledge in this area.

Positive effects when using scientific knowledge in the implementation of innovative projects and to improve the quality of higher education in the field of cyber-physical systems may arise when: there is a systematic integration of knowledge related to various fields of innovation, technology, economics, management, in the interests of creating innovative cyber-physical systems; there is a reduction in the risks of the lack of necessary scientific knowledge about the elements and the cyber-physical system as a whole; there is a customization of research in relation to the problems of developing cyber-physical systems of scientific research; there is an increase in the probability of timely finding relevant scientific knowledge; there is a formation of priority areas of scientific research in the field of cyber-

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physical systems; there is an increase in the degree of customer orientation in the scientific and educational work of universities in the field of cyber-physical systems and much more.

The formation of new innovative scientific and educational directions in this area can further increase the efficiency of the sphere of scientific support of cyber-physical systems. To increase the efficiency of the processes of creating and operating cyber-physical systems, to improve the quality of education in this area, it is proposed to form such areas of scientific and educational activities in this area: "Methods of research of cyber-physical systems (CPS)"; "Methods of program development and technology of testing cyber-physical systems (CPS)"; "Methods for analyzing the results of tests of cyber-physical systems (CPS)" (Nuhu & Onojah, 2022).

Abstract of the research program and curriculum in the direction of "Methods of research of cyber-physical systems (CPS)" may include the following didactic units: the emergence of CPS as a stage of scientific and technological progress; the concept and features of CPS; the need to develop the methodology of scientific research of CPS; the concept of scientific support of CPS research; technological platforms of CPS; features of research levels of the technological pyramid CPS; classification of CPS research methods; fundamental and applied CPS research; features of CPS research at various stages of their life cycle; description of the content of the most commonly used CPS research methods; previous, real-time and subsequent CPS research; application of design thinking methodology in the design and research of CPS; content and features of analysis and diagnosis of CPS; methods for analyzing the effectiveness of research methods in CPS and more.

The abstract of the curriculum relating to "Methods of developing programs and testing technologies for Cyber-physical Systems (CPS)" can cover the following didactic units: stages of the CPS life cycle; tests as a stage of the CPS life cycle; types of CPS tests; features of the CPS as a test object; the role of tests at all stages of the CPS life cycle; goals and objectives of CPS tests; functional CPS tests; concept and structure of CPS test technologies; technological preparation of CPS tests; methods of planning CPS tests; typical representations of CPS as a test object; organization of development of CPS test programs; development of a CPS test safety project; development of simulation environments during CPS tests; development of a measurement project during CPS tests; accompanying modeling during CPS tests; evaluation of the effectiveness of CPS test programs; completion of CPS based on test results and more.

Abstract of the scientific direction and/or curriculum "Methods of analysis of test results of Cyber-physical systems (CPS)" includes the following didactic units: analysis of CPS test results as a technological element and stage of the testing process; information support for analysis of CPS test results; technological process of analysis of CPS test results; features of CPS as an object of testing and analysis; goals and objectives of the tasks of the analysis of the results of the CPS tests; functional tests of the CPS; the concept and structure of CPS testing technologies; types of CPS testing technologies; classification and types of analysis of CPS tests; methods of accompanying modeling in the analysis of CPS test results; standard representations of CPS in their analysis; organization of analysis of CPS test results; analysis of safety of CPS; analysis of reliability of CPS; evaluation of the target effectiveness of the sample based on the results of CPS tests; analysis of sufficiency of information support of the CPS test process; analysis of completeness and effectiveness of programs tests of the CPS; formation of recommendations for the completion of the CPS based on the test results; evaluation of the effectiveness of the CPS test program and more.

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4. CONCLUSION

The methodological provisions of the design paradigm and the general theory of cyber-physical systems are developed in the work. The article discusses the basics of using ergo design to form a scientific platform for cyber-physical systems. Such a platform should be created in the interest of increasing the economic efficiency of the processes of obtaining and using scientific knowledge in the design and use of cyber-physical systems. The article highlights and describes the structural elements of the scientific platform of cyber-physical systems. The article offers academic disciplines. These academic disciplines are able to increase the quality of higher education in the field of cyber-physical systems. Such an increase in the quality of higher education can be associated with the following factors: the organization of knowledge in the form of a scientific platform; increasing the efficiency of the use of knowledge within the scientific platform; stimulating the development of systematic and ergonomic thinking of students and others.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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