System-forming aspects of computer science and mathematics teachers' readiness to develop and use computer didactic games: a comprehensive TPACK-GPCK framework analysis

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Abstract

The research, based on the actualization of the innovative paradigm, the ideas of child-centrism, and the analysis of system-formal aspects, presents the conceptualization of readiness of computer science and mathematics teachers to develop and use CDGs in the educational process. The results of a practically oriented research state of this readiness are presented, which is considered as an integrated professional and personal ability of the teacher, consisting of motivational-value, cognitive-active and personal-reflective components and is aimed at using CDGs in the educational process as a relevant innovative technology. In the system of the cognitive-activity component, the spatial aspect is analyzed. Actualization of the spatial aspect is considered as a way of revealing the phenomenology of real and virtual spaces, presented as significant pedagogical environments of cognitive-semantic and spatial-value contexts. Based on the generalization of the results of the study of motivational-value, cognitive-active and personal-reflective criteria of the readiness of computer science and mathematics teachers to develop and use CDGs, the average level of its formation was determined. Recent systematic reviews indicate that teacher readiness is fundamentally shaped by the integration of TPACK (Technological, Pedagogical, and Content Knowledge) and GPCK (Game Pedagogical Content Knowledge), with self-efficacy emerging as the strongest predictor of adoption. Our findings align with current evidence showing that 59.2% of teachers demonstrate medium-level TPACK competencies, while interdisciplinary collaboration between mathematics and computer science educators significantly enhances readiness through blended knowledge profiles. The main educational strategies aimed at improving this readiness are determined, including targeted professional development that addresses both technical knowledge gaps and confidence-building, the implementation of virtual professional learning communities (PLCs) that have shown to overcome traditional barriers, and the development of adaptive, teacher-centered game authoring platforms. Critical challenges persist, including insufficient game-specific training, resource limitations, and a notable gap between theoretical understanding and practical classroom implementation, suggesting the need for comprehensive, context-sensitive interventions.

Keywords

readiness, visual-spatial aspects, computer science teacher, mathematics teacher, computer didactic games, educational process, professional activity, life-long learning, TPACK, GPCK, self-efficacy, interdisciplinary collaboration, professional development

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1. Introduction

The current direction of today's education is creating conditions for shaping an individual who is at the same time professionally competent, socially engaged and creative. The content of the knowledge to be acquired by modern specialists, its volume, the set of skills necessary for professional activities are constantly changing and increasing. All spheres of education are searching for ways to intensify and quickly modernize the training system, improve education quality by using digital technologies as an instrument for human activities and a new and fundamentally different way of education. This led to the development of new methods and forms for the provision of education [1, 2, 3, 4, 5, 6, 7, 8, 9].

One of the most important tasks of the educational system today is to introduce educational technologies that could facilitate the formation of a creative and active personality, able to meet the challenges and to achieve the desired goals [10, 11]. The above highlights the importance of the development and implementation of different approaches to the realization of educational tasks, aimed at the development of students' creative activities.

A computer science and mathematics teacher today has to understand the efficient pedagogical technologies and effectively use digital technologies in teaching informatics [12, 13, 14, 15, 16]. The use of gaming technologies and computer didactic games (CDGs), in particular, is one of such approaches [17, 18, 19, 20, 21, 22].

The games accompany people throughout life and this phenomenon greatly attracts the interest of researchers. In the current situation, they may be a great motivation for students to learn specific subjects on the one hand and a way to facilitate teachers' work on the other.

Let's consider the pedagogical and value understanding of the phenomenon of computer games. Accordingly, we will reveal the debatable understanding of computer games as an innovative educational direction and a system of modern digital technologies that can bring qualitative changes to the educational process.

Today's teachers' succeed in mastering educational electronic resources that they use in the class [4, 23, 24, 8]. CDGs as a system of education may be an integral part of electronic educational resources. Computer didactic games present a type of electronic educational resource that targets students and functions on the basis of digital technologies, presenting a chain of tasks built on the basis of the development education. CDGs do not change but complement traditional game forms and classes, and present a natural way to attract students to the latest information technologies [6, 4, 23]. The practical application of such games demonstrates that they remain valuable educational tools as they have the following advantages [5]: a new way of working provokes students' interest in education; practical manipulation assists the processes of learning,memorization, increases cognitive abilities, enables the realization of individual learning strategies and stimulates students' capacity for research and talent; attractive sounds, actions and colors make games interesting and help students to obtain information in a user-friendly form.

Recent meta-analyses of TPACK in mathematics education reveal critical insights about the current state of teacher readiness. According to systematic reviews covering 237 studies from 2013-2022, the most researched mathematical topics in relation to TPACK include rational numbers, geometry, and algebra, with 83 unique topic-specific learning difficulties identified [25]. Furthermore, evidence from structural equation modeling studies demonstrates that contextual knowledge (XK) significantly influences TPACK development, suggesting that understanding the teaching environment is crucial for effective game integration [26]. These findings underscore the complexity of developing teacher readiness for CDG implementation, as it requires not only technological skills but also deep pedagogical understanding of how games can address specific mathematical learning challenges.

CDGs may be divided into three groups [27]:

1. *Educational.* They contribute to students' education: develop basic mathematical and computer science skills, familiarize the child with the alphabet, to obtain and improve knowledge of chemistry, physics, geography etc. (figure 1).

Figure 1: Bristar: Heroes of Math and Magic [28].

2. *Developing*. They contribute to students' cognitive development, encourage activities and independent creative work, develop memory, logical thinking, develop reading skills, etc. (figure 2).

Figure 2: Scratch: About Scratch [29].

2. *Diagnostic*. They determine the level of development of students' skills (figure 1).

The studies carried out up to now demonstrate that important skills may be acquired, developed or supported by CDGs. The spatial visualization (rotation and mental manipulation by two- and three-dimension objects), for example, improves during the reproduction of the video game [30, 4]. CDGs are a perfect environment for promoting authentic educational processes: advancing a process of learning-by-doing and thus enabling a student to control his/her own training experience; provide an experience in simulating interactive scenarios that students deal with in the real world; the use as an environment for active learning and improving task solving skills.

Conducting an overview of this problematic, we will present current directions and important results and ideas of introducing computer didactic games into the educational process.

Oliveira et al. [31] analyzed a large volume of literature (2108 studies) and presented a panoramic view of the problem, – they identified a spectrum of rather contradictory trends and educational phenomena of the use of computer games. According to the results indicated by the authors, gamification in education is studied in the following areas [31]: definition of the phenomenon of different perception of gamification design by people; increasing the involvement in activities and the effectiveness of students' activities; actualization of the variability and diversity of the implementation of educational activities; increasing interest and motivation to study; promoting the consideration of the individuality of students and their personal preferences in the learning process; actualization of the use of different learning styles; taking into account the perception and effectiveness of various pedagogical methods, orientation towards the transformation and variability of the structure of knowledge. At the same time, the authors note that gamification can produce contradictory educational results, which relate to both increasing the effectiveness of learning and motivation for it and interest in it. Important is their observation that in studies [31]: for the adaptation of educational systems, students are mainly involved only as users; there is no sufficient comparison of adapted gamification with non-personalized gamification in the works; there is insufficient evidence of the impact of adapted gamification on student experiences; cultural and gender aspects of gamification are not studied; research does not reveal the role of an adapted gamified educational environment in relation to its design. The researchers' ideas that the actualization of cultural, gender, demographic, characterological, and design aspects can affect the effectiveness of gamification are relevant. Significant in this context is the problem of personalization and design.

The effectiveness of education with electronic educational game resources in mathematics, conducted during the study "Rozumnyky" (Smart kids) is described in [32]. Researches argue that using electronic educational game resources in the educational process contributes to the improvement of students' motivation, thinking, and memory and actualizes integrative learning and the development of key and subject competencies [32].

The research publications gave consideration to the question of development and efficient implementation of CDGs or their elements into the educational process on different levels of education. Relevant in this aspect is the research of Zhaldak [33] devoted to the problem of providing educational institutions with educational software. This problem is revealed by the authors in the context of humane ideas of a harmonious combination of computer-oriented learning technologies and information culture with existing pedagogical traditions. Information technologies are also represented as one of the effective ways of humanizing the educational process and expanding the communication of its participants. Pedagogical, health-preserving and spatial aspects of the use of digital technologies, in particular, work with an interactive whiteboard, are revealed in the mentioned research.

System-organizing methodological aspects of the formation of educational technologies were considered in the research of Semerikov et al. [3] by rethinking the concepts of "methodical" and "methodologic/methodical system" and determining ways to develop a "new class of teaching methods – computer-based training systems". In particular, they built a model of a computer-oriented method of teaching informatics for future mathematics teachers, aimed at forming their informatics competence, a component of which is a method of training competences in programming and computer games development [3].

Hakak et al. [34] explore the issue of gamification based on cloud technologies. They point to the need to create a gamified learning environment and present an option for a gamified curriculum, within which different educational subjects can be integrated. From a spatial point of view, this study demonstrates an attempt to create a digital educational quasi-space as "smart", interactive and integrating different subject areas.

Based on the application of the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) methodology in three multidisciplinary databases of educational centers. Manzano-León et al. [35] conducted research on gamification. The authors indicate that gamification is an effective means of influencing the academic performance and motivation of students.

The majority of the studies in this sphere concern primary education. To a lesser extent, attention is paid to secondary and higher education. The studies have mostly been carried out based on the examples of using CDGs to learn mathematics and languages. Game is a priority activity for pre-school children and remains an active way of discovering the world for primary school children [36]. Using games in the educational process for young pupils and seniors remains less researched, since children of this age group are educated on the basis of the activities-oriented approach with the use of more formal ways of learning.

Michala et al. [37] present the benefits of using CDGs in secondary school for the development of cognitive and emotion management skills. The authors' use of Greek art and culture when using CDGs is interesting. The use of CDGs and Greek art actualizes the expressive visual-spatial aspect of learning. This reveals the significance and educational effectiveness of interconnected spatial, visual-spatial and visual-cognitive aspects.

Rybka [24] undertook a study in which she examined the phenomenon of gamification based on the example of using computer games for teaching philosophy in engineering higher educational institutions. The author identified destructive and negative phenomena in the process of using game forms, suggested ways to overcome them. She emphasizes that game practices, as those that activate and nurture emotional intelligence, are especially necessary and valuable for students studying at engineering higher educational institutions.

Research by Rocha and Barroso [7] is inclusively focused on the design and implementation of a game application for cognitive rehabilitation of children with special educational needs and the elderly. Preliminary results showed that their computer didactic game can be used as an auxiliary tool in special education and in rehabilitation.

Recent research provides compelling evidence about the critical role of Game Pedagogical Content Knowledge (GPCK) in teacher readiness. A comprehensive analysis of 376 in-service elementary school teachers reveals that GPCK directly predicts teachers' attitudes and actual use of didactic games, with junior teachers relying more heavily on GPCK while senior teachers depend more on general pedagogical knowledge [38]. This finding is particularly significant as it highlights the differential influence of experience on game-based teaching approaches. Moreover, studies utilizing structural equation modeling with mathematics teachers demonstrate that self-efficacy emerges as the strongest predictor of game-based learning adoption, interacting synergistically with TPACK-G to influence both intention and actual classroom use [39]. These insights underscore the multidimensional nature of teacher readiness, requiring targeted interventions that address both knowledge domains and motivational factors.

Determining the innovative trend and the practical-technological significance of the implementation of computer didactic games in the educational process, we actualize the problem of forming a model of the computer science and mathematics teachers' readiness to develop and use CDGs on the selection of system-forming aspects. The specified system-forming aspects are understood as methodological and conceptual prerequisites that constitute the specified readiness not only axiomatically, but through the disclosure of the multidimensional nature of the problem. We highlight the following system-forming aspects of the computer science and mathematics teachers' readiness to develop and use CDGs: innovative, cognitive-activity, personal-reflective, motivational-valuable, valuable, spatial which is considered as spatial-cognitive and visual-spatial, temporal, cultural and educational, creative, communicative. In this study, we consider the first six system-forming aspects.

The innovative aspect was considered above in the pedagogical and value understanding of the implementation of gamification in the educational process. Accordingly, this aspect represents the significance, features and direction of the introduction of CDGs into the educational process as an innovative trend. The innovative orientation of computer didactic games is realized in relation to the concept of the triangle of knowledge [40], which includes a close interaction of education, science and innovation.

The following four aspects cognitive-active, personal-reflective, motivational-valuable, valuable are relatively traditional. They are used integratively or individually when forming models of readiness, skills, and competencies. Therefore, three of the specified aspects – cognitive-active, personal-reflective, motivational-valued – are considered as its components in our model. All other aspects to one degree or another take part in the constitution of readiness.

Special attention in the development of readiness is given to the spatial aspect, which we consider practically oriented as spatial-cognitive and visual-spatial. The use of the spatial aspect in the formation of readiness is determined by the understanding of the computer science and mathematics teachers' readiness to develop and use CDGs as a complex anthropological and cultural-educational phenomenon in which spatiality and visuality are expressive and significant.

As an example, we will present a study that is close in its orientation to our readiness development. Chen et al. [41] analyze five key components of game literacy – (1) basic game literacy, (2) high-level game literacy, (3) instructional design for game learning, (4) organization and management of game-based learning, and (5) evaluation of game-based learning needed by teachers to implement game-based learning. The authors emphasize the importance of educational design when implementing game-based learning. The result of the research by Mathe et al. [42] is the conclusion that the effectiveness of the use of digital games by Swedish teachers depends on the competence and motivation of teachers for professional development, on the availability of appropriate game resources. Nousiainen et al. [43] present four basic competencies – pedagogical, technological, collaborative and creative, which are necessary for teachers to effectively implement game pedagogy.

The use of didactic games, as well as game methods and technologies in general, contributes to a deeper methodological and value understanding of the environment in which they are implemented. First of all, it concerns virtual and real space. Traditionally, space is understood as a background where the educational process is implemented. In the system of modern postmodern scientific and methodological ideas, space is like time and the processes that are in them, or rather, with their help, are implemented integratively and holistically. Currently, visual-spatial approaches that have demonstrated their effectiveness in various fields of knowledge and life practices are relevant. One of such significant practices and technologies, which for their effective implementation require the active inclusion (or at least consideration) of the "visual-spatial" factor, are games. In addition to the indicated scientific and methodological trends and practical requests, we consider the issue of the development of the computer science and mathematics teachers' readiness to develop and use CDGs in the context of actualizing the spatial factor.

Accordingly, in this methodology, from a cognitive and axiological point of view, spatial phenomena, as well as real and virtual spaces, are considered significant for the technologicalization of education and for the professionalization of mathematics and computer science teachers. In the scientific pedagogical literature, the visual-spatial aspect of the development of the computer science and mathematics teachers' readiness to develop and use CDGs is not sufficiently disclosed. This, taking into account the above-mentioned trends of modern science and the socio-cultural sphere and requests for the effectiveness of the practical implementation of game-based learning methods, defines the researched problem as urgent.

For the methodological understanding of space, including virtual and spatial phenomena, the work of Avetysian [44], which reveals the meaning and nature of visuality, is relevant. In this study, the authors turn to the classical ideas of visuality by Merleau-Ponty [45] and Deleuze [46]. At the same time, they emphasize ideas about: the semantic independence of the visual dimension of culture from language, the principle of the activity of a visual object, the peculiarities of the viewer's interaction with visual phenomena. Thanks to these ideas of visuality, we understand space not as a background against which certain events take place, but as a special spatial world with active spatial phenomena. From the cultural and educational point of view, the application of the presented ideas of visual theory for the development of the teacher's readiness to use didactic games is relevant. This is due to the fact that the visual-spatial aspect in the specified computer technology is one of the system-organizing factors.

In the theoretical and technological aspects of the application of the spatial approach and the idea of visuality, research by various authors is relevant.

Briantseva [47] reveals the peculiarities of designing digital didactic visual tools. Bäckman and Pilebro [48] present a study conducted within the framework of visual pedagogy, the results of which indicate improved cooperation during dental treatment in preschool children with autism. Du et al. [49] present ways of helping children with autism spectrum disorder in teaching dental care based on the use of visual pedagogy tools. Drushliak [50] reveals the significance and features of visual information culture of future mathematics and computer science teachers and presents its model. Aiello and Parry [51] reveal the features of visual communication. They emphasize the idea close to us, that visuality and visual means are a significant aspect of many disciplinary scientific and practical spheres. At the same time, the importance of visuality is not sufficiently realized. Goldfarb [52] considers visual pedagogy, visual technology as relevant directly in the education and life of people, as it needs further purposeful development.

In scientific literature, the issue of developing the computer science and mathematics teachers' readiness to develop and use CDGs is insufficiently disclosed. Issues of actualization of spatial aspects in the system of the specified readiness, both during its development and during implementation, are not sufficiently disclosed. Taking into account the importance and innovativeness of the use of computer didactic games for the implementation of the processes of technologization, virtualization, digitalization, axiologisation, humanization of education, as well as for the development of the professionalization of the teacher and the formation of his innovative culture, the specified problem is presented as an actual.

The *purpose* purpose of the research is to study the value, cognitive-activity, personal-reflective and visual-spatial aspects of the computer science and mathematics teachers' readiness to develop and use computer didactic games.

2. Selection of methods and diagnostics

Information on how CDGs are being developed and used in the educational process was generated following the results of the analysis of public educational standards [53], typical educational programs, curricula, other normative documents, methodological works of teachers and literature sources. Analysis as for the computer science and mathematics teachers' readiness to develop and use CDGs in the educational process was carried out by using empirical research methods (observation of teaching activities, questionnaires, interviews), as well as verbal-communicative and psychodiagnostic research methods.

The research used a system of methods and approaches. Axiological, systemic, spatial, visual-spatial, cognitive-spatial, psychological, anthropological, and teleological [54] approaches were used. The methods of mathematical statistics, in particular, descriptive statistics, cluster analysis, were used to process the research results. To develop a model of the computer science and mathematics teachers' readiness to develop and use CDGs, the method of pedagogical modeling was used.

The readiness of computer science and mathematics teachers to develop and use computer didactic games was determined on the basis of three generalizing criteria. The names of the three criteria correspond to the three components of this readiness. Thus, we distinguish the following criteria: motivational-valuable, cognitive-active, personal-reflective. Accordingly, these criteria reflect the contents and meanings on the basis of which the components of readiness are formed. The criteria were determined as a result of the use of various diagnostic methods, including the author's, as well as by analyzing the educational achievements of teachers. Each criterion is characterized by three levels (low, medium, high) of the formation of a certain component of readiness. The results were summarized and interpreted based on the criteria. According to each criterion, we characterized the level of formation of its indicators. According to each criterion for evaluating the computer science and mathematics teachers' readiness to develop and use CDGs in the educational process, we characterized the level of formation of its indicators.

Motivational-value criterion:

- Low: there is no interest in the development of CDGs; there is a fragmented and limited interest in certain topics; lack of motivation and interest in using CDGs; the selection of CDGs is random; there is no interest in training in the use and development of CDGs.
- Medium: existing interest in the development of CDGs, related to the results; there is a responsible attitude to learning in the absence of creative activity; formal interest; motivation is due to the need to implement CDGs; existing interest in the application of CDGs in professional activity, related to its results; there is a responsible attitude to training in the development and use of CDGs; lack of understanding of the benefits of using CDGs in professional activities; episodic manifestation of creative activity.

- High: Internalization and awareness of the values of this activity, purposefulness in the implemented CDGs, formation of educational and cognitive motives, existing motivated and responsible attitude to the use of CDGs in the educational process, awareness of the educational and innovative significance of cognitive motives, systematic manifestation of creative activity, orientation towards achieving success, professional orientation for self-improvement; conscious choice of this didactic tool; training in the development and use of CDGs for the purpose of professional growth; motivated professional focus on the development and application of modern CDGs.

Cognitive-active criterion:

- Low: low level of knowledge on the development and use of CDGs, their low reproducibility, lack of systematicity; solving simple typical tasks with the help of others; the ability to use modern CDGs in professional activities is partially fragmentary in nature; fragmentary cognitive needs, interests, motives for developing and using CDGs.
- Medium: the average level of knowledge on the development and use of CDGs (partial system knowledge) and their fragmentary reproducibility; solving standard tasks on the development and use of CDGs with the help of others; the ability to independently solve the issue of choosing a CDGs is not inherent; the presence of cognitive needs, interests, motives for the development and use of CDGs.
- High: high level of knowledge (systemic, creative nature), knowledge of development and use of CDGs; the ability to independently solve typical problems, solving non-standard problems, full reproducibility, independent search for solution methods, the ability to generate new approaches in the development and application of CDGs; the ability to master modern knowledge, generating ideas, creativity in solving tasks, the ability to independently master the means of modern CDGs, the search for and use of innovations, independent assessment of the appropriateness of the selection of modern CDGs; available cognitive activity, the desire to master modern knowledge, the availability of methods of scientific research activity, the professional orientation of cognitive activity in theoretical and practical activities; independent solving of problems of professional orientation of medium and high levels of complexity of development and use of modern CDGs tools; the presence of elements of creativity in solving problems, the ability to analyze, synthesize and establish relationships between socio-economic phenomena and processes; solving non-standard professional tasks, tasks of a high level of complexity; creative approach to solving; critical, contextual thinking; independence in assessing compliance and choosing tools of modern CDGs in solving professional problems; independent mastery of modern CDGs in order to solve professional problems, ability to work in a team.

Personal-reflectiv criterion:

- Low: there is a fragmented ability to introspect; inability to plan activities in the process of developing and using CDGs; low capacity for self-control and self-regulation; there are inefficient methods and methods of organizing this activity, which are not purposefully formed; awareness of the content of the activity has a fragmentary spontaneous manifestation; in the vast majority of cases, the quality of performed tasks is inadequately assessed; fragmentary, random manifestation of the ability to self-educate; inability to independently master material on CDGs.
- Medium: the presence of self-analysis skills, which is mainly manifested under the influence of external factors; existing activity planning for the development and use of CDGs and the ability to self-monitor and self-regulate in individual cases, mainly under the influence of external factors; there is a fragmentary manifestation of one's own style of activity in the development and use of CDGs; separate manifestations of a conscious and purposeful own style of activity; awareness of the content of the activity and possessing the ability to evaluate and ensure the quality of the work performed on the development and use of CDGs; there is a non-systematic manifestation of the ability to independently master the material of individual topics on the development and use of CDGs.

- High: implementation of a conscious and adequate self-analysis, awareness and prediction of the results and consequences of the development and use of CDGs; existing planning of activities for the development and use of CDGs and the ability to self-monitor and self-regulate; cognitive abilities aimed at self-development; self-organizations that are managed and initiated by the individual himself; available skills to independently overcome obstacles; the characteristic deepness of the self-organization process in the system of activities for the development and use of CDGs; there are effective techniques and ways of organizing one's own style of activity for the development and use of CDGs, its conscious and purposeful formation with elements of creativity and innovation; awareness of the content of the development and use of CDGs and the ability to evaluate and ensure the quality of the work performed; the ability to determine promising directions for the development and use of the latest CDGs in professional activities, possessing the skills to choose and use modern CDGs tools; capable of self-education in this direction; the ability to implement knowledge, skills and abilities to achieve the goal of professional activity in the development and use of CDGs; the ability to self-realize, systematic, persistent manifestation, the ability to achieve success in this activity.

The following techniques were used in the research: "Diagnostics of motivation for success and fear of failures" [55]; tests and questionnaires on determining levels of formation of motivational-value, cognitive-activity and personality-reflexive components; "Self-controlling Abilities" [56]; "Self-Efficacy Test" [57]; "Research of Strong-willed Self-regulation" [58].

Questionnaires were used in the research: Questionnaire for determining the computer science and mathematics teachers' value orientations as for the development and implementation of CDGs in educational process (developed by Klochko [59] on the basis of Rean et al. [55] method); Questionnaire for diagnostics of motivation for success and fear of failures [55]; Questionnaire for determining the significance of readiness for the development and implementation of CDGs for successful professional activities [60, 61]; Questionnaire to determine the percentage distribution of computer science and mathematics teachers by levels of the ability to self-governance [56, 57, 58]; Questionnaire for determining the indicators of cognitive-activity criterion of evaluation of computer science and mathematics teachers' readiness to develop CDGs and implement them into the educational process (developed by Klochko [59] based on Raven [62] methods); Questionnaire to determine the percentage distribution of computer science and mathematics teachers by levels of the ability to self-control [56, 58]; Questionnaire for determining the Indicators of personality-reflexive criterion for evaluation of computer science and mathematics teachers' readiness for CDGs development and implementation (developed by Klochko [59] based on Rean et al. [55] methods); Fedorets-Klochko questionnaire for determining the value interpretation of space by computer science and mathematics teachers.

The *"Questionnaire for determining the computer science and mathematics teachers' value orientations as for the development and implementation of CDGs in educational process"* contained the following questions (developed by Gurevych et al. [63] on the basis of Rean et al. [55] method):

1. Achieving professional success.
2. Developing personal strengths and abilities.
3. Acquiring professional and information competencies.
4. Providing material comfort.
5. Achieving recognition and respect in professional sphere.
6. Improvement of social status.
7. Striving to new achievements.
8. Self development and self improvement.
9. Recognition and respect of managers.
10. Achieving students' respect.
11. Developing students' interest to computer sciences.
12. Possibilities to show one's potential.
13. Possibility to improve pedagogical skills.

14. Possibilities to introduce new methods and forms of activities.

Respondents answered the questions of the questionnaire in accordance with two areas – development of CDGs and introduction of CDGs into the educational process.

The *"Questionnaire for determining the indicators of cognitive-activity criterion of evaluation of computer science and mathematics teachers' readiness to develop CDGs and implement them into the educational process"* contained the following questions (developed by Gurevych et al. [63] based on Raven [62] methods):

I. According to the development of CDGs:
   1. I am aware.
   2. I have knowledge.
   3. I have skills.
   4. Able to develop.
   5. Realize didactic peculiarities.
   6. Realize basic functional possibilities.
   7. Realize basic requirements to development.
   8. I know how to select topics.
   9. I can develop design.
   10. I know peculiarities of psychological influence on age groups of children.
   11. I know how to classify games.
   12. I know the basic classes of software.

II. According to the implementation CDGs into the educational process:
   1. I am aware.
   2. I have knowledge.
   3. I have skills.
   4. Able to use.
   5. Realize psychological peculiarities.
   6. Realize basic functional possibilities.
   7. Realize basic requirements to implementation.
   8. I know how to select games aimed at attaining lesson's goal.
   9. I know how to select games aimed at realization of person-centered approach.
   10. Implement with the aim to ensure cross curriculum connections.
   11. I know how to classify games.
   12. I know which software to use in this sphere.

The *"Questionnaire for determining the Indicators of personality-reflexive criterion for evaluation of computer science and mathematics teachers' readiness for CDGs development and implementation"* contained the following questions (developed by Klochko [59] based on Rean et al. [55] methods [63]):

I. According to the development of CDGs:
   1. I am a qualified developer.
   2. I strictly determine a purpose of the development.
   3. I work much to improve competencies.
   4. I want to achieve high results.
   5. I know my weaknesses and strive to improve them.
   6. I constantly search for new methods, forms and ways for realization.
   7. I know what to work with and what to learn in the nearest future.

II. According to the implementation CDGs into the educational process:
   1. I am a qualified user.
   2. I strictly determine a purpose of implementation.
   3. I work much to improve competencies.
   4. I want to achieve high results.
   5. I know my weaknesses and strive to improve them.

6. I constantly search for new methods, forms and ways for realization.
7. I know how to use and look for necessary means.

The methodology is aimed at actualizing and revealing the spatial aspect of computer science and mathematics teachers' readiness for the development and use of computer didactic games. In this work, to reveal the phenomenology of CDGs, we turn to their understanding and application not only in the mental-semiotic and cognitive-operational planes, but as a spatial or, more precisely, "cognitive-spatial" phenomenon. The specified methodological insights correspond to the ideology of the "visual turn" and "spatial turn" in the methodology of science. A significant aspect of considering the indicated methodological trends, as significant, is that we can purposefully represent virtual reality, first of all, as a special informational and meaning-making space. It is important to understand the real physical space also as a special content-semantic or "cognitive-spatial" field, as a meaningful background or context actively included in the educational process. Accordingly, the use of digital technologies of virtual reality with the active participation of the teacher contributes to the "transformation" of physical space into the content-semantic or "cognitive-spatial" field of the educational process. In our opinion, the decisive factor in the specified "cognitive transformations" of virtual reality and real space is the use of game methods. In our opinion, this is due to the fact that in the semantics of the game in its semantic contexts, the spatial component is relevant but at the same time "hidden". The game, which first appears in childhood, is primarily aimed at the child's understanding of himself as a spatial phenomenon, as well as at revealing his ability to navigate in space, which, accordingly, are cognitive processes. Such a cognitive manifestation of life corresponds to the idea of autopoiesis of Maturana Romesín and Varela [64]. These authors interpret life as a cognitive autopoietic process. Accordingly, we expand and refine the specified understanding of Maturana Romesín and Varela [64] to this educational context. We can note that for a person it is also a spatial and visual process. In this work, a "Fedorets-Klochko questionnaire for determining the value interpretation of space by computer science and mathematics teachers" was developed to analyze the understanding of computer science and mathematics teachers about space as a special educational value, space as a possible tool for the intellectual development of a child, space as a background and a component of didactic games. An important methodological prerequisite for the development of this questionnaire was the idea of contextual learning, which can be interpreted as follows: a teacher who understands the surrounding environment, including space, as a way, as a condition or even as a "soft" teaching tool, will be more effective, competent and according to the nature of the child, use CDGs and other methods, in the implementation of which the spatial aspect is relevant.

The *"Fedorets-Klochko questionnaires for determining the value interpretation of space by a teacher of mathematics and computer science"* contained the following questions:

1. The purposeful use of space and spatial phenomena is an important pedagogical condition for effective disclosure of the content of educational material in mathematics and computer science.
2. The use of virtual space, augmented reality and digital technologies is a important pedagogical condition for the effective disclosure of the content of educational material in mathematics and computer science.
3. An integrative consideration of spatial phenomena and virtual space as meaning-forming and system-forming factors of the educational process is relevant for effective learning.
4. Virtual space, as well as real space, can be considered as a meaning-making matrix when implementing game-based learning methods.
5. The game-learning methods and actualization of phenomena of real space and virtual reality are presented as conceptualization tools that form a metaspace of meanings in the study of mathematics and computer science.
6. In order to improve the efficiency of professional activity, the teacher should apply the phenomena of real space and virtual reality in order to present the educational material logically in an "expanded" and illustrative format.
7. Both real and virtual space have their own metalogic, which is revealed when using game methods.

8. Game learning methods and animation reveal the meaning-making aspect of real and virtual space, which can be purposefully applied in the study of mathematics and computer science.
9. The possibility of actualizing the phenomena of real space and virtual reality is considered as an instrumental value in the professional activity of a teacher of mathematics and computer science.
10. The actualization of the phenomena of real space and virtual and augmented reality corresponds to the spatial essence of human nature.

We will present the ideas and content-semantic aspects underlying the "Fedorets-Klochko questionnaire for determining the value interpretation of space by computer science and mathematics teachers". This questionnaire is aimed not only at diagnosing the teacher's value interpretation of real and virtual space, but also at actualizing spatial issues as significant in the study of mathematics and computer science. The reflective aspect of this questionnaire is also important, which reveals to the teacher ways of understanding spatial phenomena as educational and life values (in particular, the value of harmonization).

Question № 1 – "The purposeful use of space and spatial phenomena is an important pedagogical condition for effective disclosure of the content of educational material in mathematics and computer science" – defines and actualizes the problems of real physical space represented as a "pedagogical tool" and a pedagogical condition for studying mathematics and computer science. It is clear that the real space becomes such a "pedagogical tool" by transforming into an educational semantic and meaning-forming context (space) by integrating the semiotic field of the lesson. This happens with the purposeful application of various educational methods (in particular, game ones) during the implementation of which spatial phenomena are actualized.

Question № 2 – "The use of virtual space, augmented reality and digital technologies is a important pedagogical condition for the effective disclosure of the content of educational material in mathematics and computer science" – purposefully defines and actualizes the problems of virtual space, represented as an established pedagogical environment and at the same time digital technology, which is used for learning mathematics and computer science. Virtual space by its very nature is an intellectual product and, accordingly, can be considered as an operational and educational environment and, accordingly, a field of knowledge and meanings. An important ant aspect of this virtual space is that it can largely model the real space one as it corresponds to human nature, including spatial thinking, the prerequisite for the formation of which is a developed human visual analyzer.

Question № 3 – "An integrative consideration of spatial phenomena and virtual space as meaning-forming and system-forming factors of the educational process is relevant for effective learning" – defines and actualizes the issue of the integrative application of virtual space and real space phenomena as a pedagogical condition and a "spatial" component of mathematics and computer science learning technologies. The methodological meaning of this question is the idea that the purposeful integrative application of technologies of both virtual space and phenomena of real space should give a synergistic and harmonizing educational effect. In children it is necessary to actualize mathematical thinking through visual perception and mathematical interpretations of the "world of things", "the world of geometric figures", "the world as a three-dimensional space" through the application of landscape pedagogy and through the visual disclosure of the phenomenology of the real world. As additional effects, it can be noted that this will also contribute to the preservation of physical and psychological health and aestheticization of the educational process. The specified "work" with real space in combination with the use of virtual space should form the student's understanding of virtual reality as a special tool and the world included in the real world. If the specified harmonization is not carried out, then the opposite effect is possible – the real three-dimensional space, as well as the world as a whole, will be considered by the student as a component of the virtual. This, in addition to the negative impact on the psyche, will not give the opportunity to fully reveal the student's cognitive potential. Therefore, in the educational process, according to the ancient Greek idea about the harmonious nature of man, between virtual reality and real space and the world, not competitive interactions should be formed, but synergistic, complementary and harmonious interactions.

Question № 4 – "Virtual space, as well as real space, can be considered as a meaning-making matrix when implementing game-based learning methods" – reveals the anthropobiological dimension of the teacher's understanding of spatial phenomena. Accordingly, within the semantic framework of this question, the space is simultaneously considered: inactively as a neutral background or condition where the game is implemented, and also as an active learning tool – as a specific context filled with contents and meanings.

Question № 5 – "The game-learning methods and actualization of phenomena of real space and virtual reality are presented as conceptualization tools that form a metaspace of meanings in the study of mathematics and computer science" – presents game learning methods not only as activity-cognitive, but also as cognitive-spatial learning phenomena, which can form "quasi-spaces" (spaces of meanings) that participate in the development of informatic and mathematical meanings and concepts.

In question № 6 – "In order to increase the efficiency of professional activity, the teacher should apply the phenomena of real space and virtual reality in order to present the educational material logically in an "expanded" and illustrative format" – the physical characteristics of spatial reality (first of all, length) are reflected. Virtual reality is developed based on the transformation of the characteristics of real space. This can be represented as the "logic of space" and, accordingly, consider spatial phenomena in the format of "didactics of space", which real space determines due to its length (according to Descartes [65]). From the standpoint of pedagogical psychophysiology, we interpret the concept of an expanded representation of educational material, first of all, as a demonstration of certain features, regularities, phenomena, both spatial structures and relationships between them. For example, the process of multiplication or addition can be depicted as subject operations in the spatial and subject fields. This will be an expanded format that clearly illustrates a certain arithmetic operation through "spatial logic". In this case, we demonstrate the indicated operations in detail. As the indicated operation is understood, it is "transferred" into the symbolic space. The specified aspect of "transfer" to the middle (interiorization into mental reality) leads to the phenomenon of "collapse" whose essence is that operations that were represented through the "logic of space" and the "logic of object actions" (for example, the close location of two groups of objects in "spatial semantics" of which was interpreted as addition) are transformed into a certain generalizing symbol in which the cognitive operation itself (for example, revealed during the demonstration of the operation with the help of objects) may no longer be displayed as spatial interactions (location). The specified features of the actualization of the subject field and the understanding of space as a meaning-making context are presented in the classical concept of the step-by-step formation of mental actions by Gal'perin [66].

In question № 7 – "Both real and virtual space have their own metalogic, which is revealed when using game methods", game methods are represented as actualizing and revealing the "multidimensional" – semiotics, axiology and contextuality of space (real and virtual). These game methods essentially transform the real space into the quasi-space of the game by "filling" it with specific meanings. Real or virtual space becomes a semiotic-symbolic field in which and thanks to which the specified game is implemented, forming conceptualization skills in the child, which are transformed into components of mathematical thinking.

Question № 8 – "Game learning methods and animation reveal the meaning-making aspect of real and virtual space, which can be purposefully applied in the study of mathematics and computer science" – points out the importance of the purposeful use of real and virtual space for the representation of mathematical and informational phenomena. That is, consideration of the structure of space and the objects that fill it as environmental prerequisites for the development of mathematical thinking of rational-logical and multidimensional and systemic external and internal realities is actualized.

In question № 9 – "The possibility of actualizing the phenomena of real space and virtual reality is considered as an instrumental value in the professional activity of a teacher of mathematics and computer science" – space is revealed as a special instrumental value that can underlie the formation of meanings and goals of educational activities. In the specified question, ideas about space are presented as a valuable context of educational practices.

Question № 10 – "The actualization of the phenomena of real space and virtual and augmented reality corresponds to the spatial essence of human nature" – reflects the phenomenology of man as a spatial being. In this issue, human nature is considered multidimensionally and, accordingly, space is presented as a prerequisite and component of human physicality and its intelligence. This cognitive understanding of space and the corporeality associated with it corresponds to the ideas of Lakoff and Johnson [67] on corporeal mind and corporeal cognitivism. This question is aimed at understanding a person in whom his integrity and physical and intellectual-spiritual essence has a significant and systemic spatial aspect, which accordingly forms an anthropic image of a person who is harmonized with the world. That is, human nature is related to nature as such. The idea of "anthropo-spatial" and "spatial-cognitive" intentionalities of a person, which must be revealed in the conditions of the educational process, is embedded in this general question.

The processing of the survey results was carried out using cluster analysis in order to identify groups of respondents and to determine ways of forming and improving the computer science and mathematics teachers' readiness to develop and use CDGs in the educational process. Cluster analysis was performed using the SimpleKMeans method and the Weka framework for data analysis and machine learning [68]. We described the SimpleKMeans algorithm in the research [69, 70]. Dunn, DB, SD, CDbw and S_Dbw algorithms were used in the process of data preprocessing in order to determine the recommended number of clusters [71, 72] (table 1). The structure with the number of clusters 4 was chosen as the best in terms of compactness and resolution.

Table 1
Optimal number of clusters, calculated with the help of quality indices.

Index	Algorithms SimpleKMeans
Dunn	4
DB	4
SD	3
CDbw	3
S_Dbw	5

The study was conducted in two stages: Stage I – 2017-2020, 183 computer science and mathematics teachers from different regions of Ukraine participated in the study [63]; Stage II – 2022, 123 computer science and mathematics teachers from different regions of Ukraine and Republic of Moldova participated in the study.

3. Results and discussion

The central theoretical result of this research is the formation of a model of the computer science and mathematics teachers' readiness to develop and use CDGs in educational process. In addition to the axiomatic and systematic approach, which includes the development of the field of problematization with the selection of the main aspects of the problem, the specified issue is solved by conducting research (presented below) (figure 3).

The development of this readiness model is based on teleological (target), anthropological and systemic approaches. Within the framework of the teleological approach, the harmonious, innovative development of the personality, which includes the formation of key and digital competencies, is considered as a prerequisite for the realization of the sustainable development goals and the innovative trend.

This model of readiness of the computer science and mathematics teachers' readiness to develop and use CDGs is based on the pedagogical value and teleological understanding of the main aspects. The specified aspects are considered as system-forming in the development of this readiness. We distinguish the following system-forming aspects – innovative, cognitive-active, personal-reflective, motivational-value, valuable, spatial, which is considered as spatial-cognitive and visual-spatial, temporal, cultural-educational, communicative aspects (figure 3). Let's consider these aspects in more detail.

Among the specified aspects, we consider cognitive-active, personal-reflective, motivational-value aspects as "internal" or anthropological, as such, which can be present in the mental reality of a professional personality. Based on the actualization and selection of the specified aspects as professionally

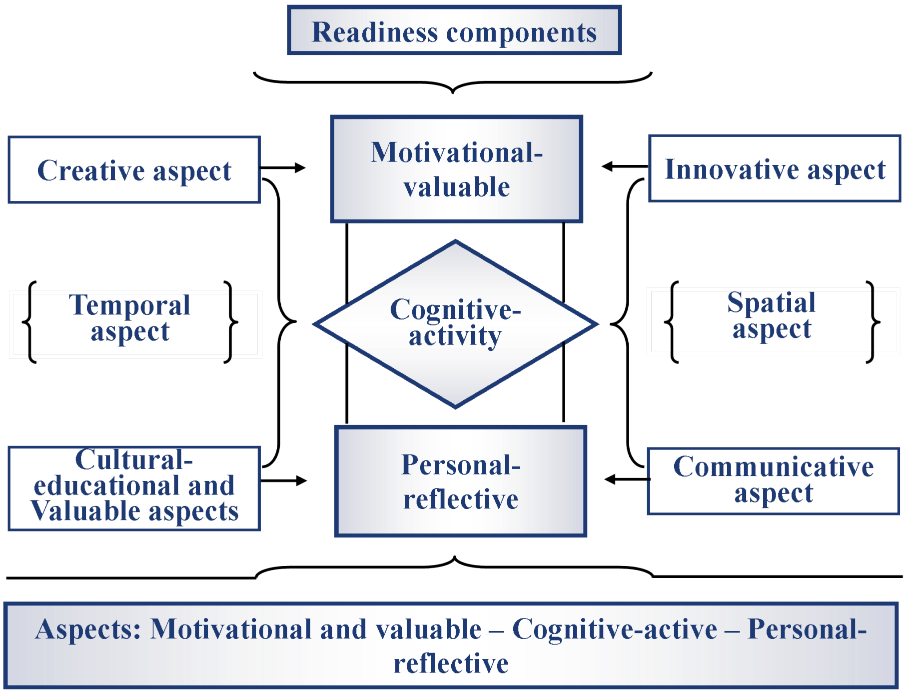

Figure 3: System-forming aspects of the model of the computer science and mathematics teachers' readiness to develop and use CDGs.

significant, a structure of readiness is developed. The specified aspects correspond to the name of readiness components and reflect the corresponding professionally significant meanings and directions. The specified "internal" aspects are formed on the basis of activity-semantic and teleological integration of individual aspects: cognitive, activity, personal, reflective, motivational, value. Such integration of the specified aspects reflects deep professionally significant features, which we present below.

The integrated cognitive-activity aspect in the readiness model is transformed into its component of the same name. It reflects the cognitive and functional specifics of the professional activity of a teacher of mathematics and informatics and the peculiarities of the intellectualized process of studying these disciplines.

The personal-reflective aspect, which in the readiness model is transformed into the component of the same name. He characterizes reflection as a defining professional ability of a computer science and mathematics teachers, which is necessary when studying the specified educational disciplines. Reflexivity in this aspect is a professional ability that determines the personal and professional potential, in particular, for the implementation of control and verification of logical operations. Therefore, reflexivity, both as a cognitive and as a personal quality, is quite developed among specialists in mathematics and computer science. For its realization, reflexivity must be deeply included in the being of a professional, in his personality. Accordingly, the specified specialists should be capable of long-term, psychologically exhausting work on finding optimal solutions, which includes purposeful activities to correct possible errors.

The motivational-value aspect, which in the readiness model is transformed into the component of the same name, reflects the humanistic and human-oriented idea of professionalization of a specialist based on meaningful and internalized (that is, transferred to the inner mental reality) values, meanings, images, intentions, etc. That is, the actualization of the specified aspect and the component of readiness corresponding to it is a way of axiologising and a manifestation of humanistic, by its essence, pedagogy, which is based on values. In this aspect, the idea of "internal motivation" is implemented in accordance with the self-determination theory [73].

In addition to those presented above, let's consider other relevant aspects, on the basis of which the readiness of the computer science and mathematics teacher to develop and use computer didactic games is formed – innovative, valuable, spatial (considered as spatial-cognitive and visual-spatial), temporal, cultural, educational, communicative.

Due to the actualization of the innovative aspect, the technological-innovative and socio-cultural significance of CDGs for the education of the future, which is the education of sustainable development, is problematized and revealed. CDGs are an innovative technology, the implementation of which in the educational process aims to move to a qualitatively new level of education. The innovative aspect is also a determining goal (telosom) in developing the computer science and mathematics teachers' readiness to develop and use CDGs. The innovative aspect, which is primarily explicit ("external") in relation to the personality-professional during its internalization (transfer into mental reality), is considered as part of the cognitive-activity component of readiness. Possession of the educational theory and practice of the application of CDGs largely reflects the innovativeness of the teacher as a professional quality and as his focus on self-development and creativity. It is significant that innovativeness is also considered as a value reference point in the process of implementing CDGs.

The value aspect is primarily an external factor of the cultural and educational space. When internalizing the value aspect, it is considered as part of the motivational-value component of readiness, and in the system of the cognitive-activity component in the format of value-oriented knowledge. The value aspect determines the meanings and orientations that are significant in the readiness system.

The cultural and educational aspect reflects the importance of professional and cultural contexts and professionally significant potentials of the educational environment in which readiness is developed and implemented. Guided by the anthropological ideas of Hall [74, p. 10-11] about the contextuality of cultures, we believe that the cultural and educational aspect is a defining professional context. The cultural and educational environment contains values, meanings, stereotypes of interaction, communication and behavior, ideas, directions, etc. in a contextual format. The development of readiness includes cultural-educational, value-semantic contexts and significant ideas that are present in them. Currently, there are ideas of direction of innovation, child-centeredness, humanization, technologization, non-violent communication, tolerance, freedom, democracy, professionalization, etc.

The communicative aspect contributes to the consideration of CDGs during their development and implementation as a special professional and communicative phenomenon, as a way of transferring knowledge, ideas and technologies. This is due to the fact that the game includes an expressive communicative aspect and can be interpreted as a way of communication. Therefore, communicability is primarily embedded in the structure of CDGs and the system of readiness itself and in all three of its components.

The creative aspect contributes to the consideration of CDGs and their implementation in the educational process as a creative phenomenon, which at the same time also contributes to the disclosure of the creative potential of an individual. Creativity, in turn, is impossible without spontaneity, a certain creative freedom, interpretability, social activity and, thus, it is a guide to the ideas of democracy and freedom as existential and educational values. Accordingly, the development of the implementation of CDGs in the educational process is a way of revealing creativity. We consider the creative aspect of readiness as part of the cognitive-activity component.

The temporal aspect actualizes the idea that CDG is a temporal phenomenon, which is important to take into consideration during their development and implementation. In turn, CDG, due to its temporal specificity, can contribute to the development of temporal competence, provided that the temporal aspect is purposefully actualized.

The spatial aspect is significant due to the fact that CDGs have a distinct spatial dimension, which must be taken into consideration during their development and implementation. We consider the spatial aspect as spatial-cognitive and visual-spatial. The spatial-cognitive aspect is aimed at developing the teachers' ability to use spatial phenomena in the educational process for the representation and illustration of educational material. The visual-spatial aspect is aimed at forming the ability to work with spatial phenomena, which includes their comprehension and interpretation. This aspect is also aimed at the development of visual-spatial intelligence. We consider the visual-spatial aspect of internalization into the mental reality of a professional personality within the framework of the cognitive-activity component of readiness.

Concluding the theoretical consideration of this problem, we will present the determination of the computer science and mathematics teachers' readiness to develop and use CDGs in educational process. By the computer science and mathematics teachers' readiness to develop and use CDGs, we understand the integrated cognitive-activity professional-personal ability of the teacher, which contains expressive value-motivational and reflective components and is aimed at implementation CDGs into the educational process, and is also implemented on the basis modern directions – innovative development, humanism, child-centrism, creativity, communicativeness, and taking into account spatial-temporal and cultural-educational specifics.

Table 2 presents a synthesized comparison of TPACK components across disciplines and experience levels, derived from multiple studies [75, 76, 77]. The data reveals that while both mathematics and computer science teachers demonstrate high content knowledge (CK), significant gaps exist in their technological pedagogical content knowledge (TPCK), with mean scores below 3.0 on a 5-point scale. Junior teachers show higher technological knowledge but lower pedagogical content knowledge compared to their senior counterparts, suggesting the need for differentiated professional development approaches.

Table 2
Distribution of TPACK components by teacher experience and discipline.

Component	Mathematics	Computer Science	Junior (<5 y)	Senior (>10 y)
TK (technology knowledge)	2.65	3.12	3.21	2.76
PK (pedagogical knowledge)	3.24	2.89	2.78	3.45
CK (content knowledge)	4.38	4.45	3.98	4.52
TPK	2.51	2.92	2.95	2.61
TCK	2.73	3.38	3.42	2.88
PCK	3.51	3.42	3.21	3.78
TPCK	2.48	2.81	2.89	2.54

Let's proceed to consider the results of the study aimed at determining the state of the computer science and mathematics teachers' readiness to develop and use CDGs. The study was conducted to establish the presented readiness structure.

The authors analyzed the results of the evaluation of the components that constitute the readiness of computer science and mathematics teachers to develop and use CDGs into the educational process.

To evaluate and analyze the levels of components of the computer science and mathematics teachers' readiness to develop and use CDGs into the educational process, the following criteria were used: the motivational-value criterion, the cognitive-activity criterion, the personality-reflexive criterion.

The specified criteria integratively characterize the same name corresponding readiness components.

Motivational-value component of readiness. Accordingly, the motivational-value criterion characterizes a set of values, meanings, intentions, motives. The awareness of these motives, values and meanings is also important.

Interviewing, questioning and testing were used in the evaluation of the motivational-value criterion of computer science and mathematics teachers' readiness to develop and use CDGs in the educational process [63]. During questioning, we were trying to realize to what extent the activities related to the development and implementation of CDGs are understandable, relevant, necessary and desirable (among the survey questions diagnostically significant were the following: "Do you agree that readiness for the development and implementation of CDGs is an important component of professional and information competencies of today's computer science teachers?", "Is it interesting for you to learn the way of developing and implementing CDGs in the educational process more deeply?").

We also used the "Questionnaire for determining the significance of readiness for the development and implementation of CDGs for successful professional activities" [60, 61]. Teachers' responses showed that teachers are aware of the importance of readiness for the development and implementation of CDGs for the successful professional activities (high level – 30,4 %, average – 50,1%, low – 19,5% of teachers) [63] (see figure 4).

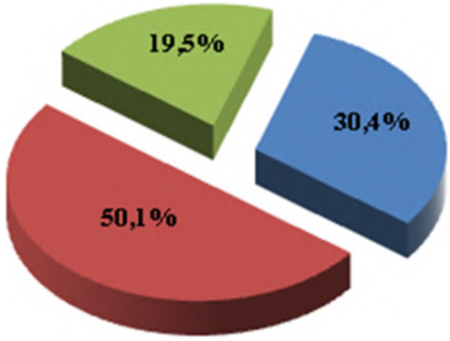

Figure 4: Significance of readiness for the development and implementation of CDGs for successful professional activities (high level – 30,4%, average – 50,1%, low – 19,5% of teachers) [63].

Value orientations, which had become a subject of study, also contribute to the achievement of professional success in teaching computer science and mathematics. For their diagnostics, the "Questionnaire for determining the computer science and mathematics teachers' value orientations as for the development and implementation of CDGs in educational process was used" (developed by Klochko [59] on the basis of Rean et al. [55] method) (table 3, figure 5).

Table 3
Hierarchy of computer science and mathematics teachers' value orientations as for the development and implementation of CDGs in educational process. (The question number column is labeled "№".)

№	Rating indicators of the development of CDGs	Rating indicators of the using of CDGs
1	4	6
2	4	5
3	4	9
4	13	13
5	10	11
6	14	14
7	9	7
8	2	4
9	12	12
10	11	10
11	2	1
12	7	7
13	8	3
14	1	1

Thus, understanding the importance of the development and implementation of CDGs into the educational process, the dominating values of teachers are the following: possibilities to introduce new methods and forms of works with students, develop students'interest to computer sciences, possibility to improve pedagogical skills in using CDGs, self-development, self-improvement as well as achieving professional success, development of personal strengths, talents, acquiring professional and information competencies in developing CDGs. The analysis of discrepancies showed that teachers give more priorities to using CDGs in the educational process ratherthan developing them. In addition, the sphere of CDGs development is of higher priority than their implementation for acquiring professional and information competencies.

Such results may mean that teachers do not fully realize the possibilities of professional growth in develop and using CDGs and do not comprehend all possibilities and ways for improving their teaching skills. It may be assumed that computer science and mathematics teachers are sufficiently oriented in the process of implementing new methods and forms of works in the classroom. They know how to

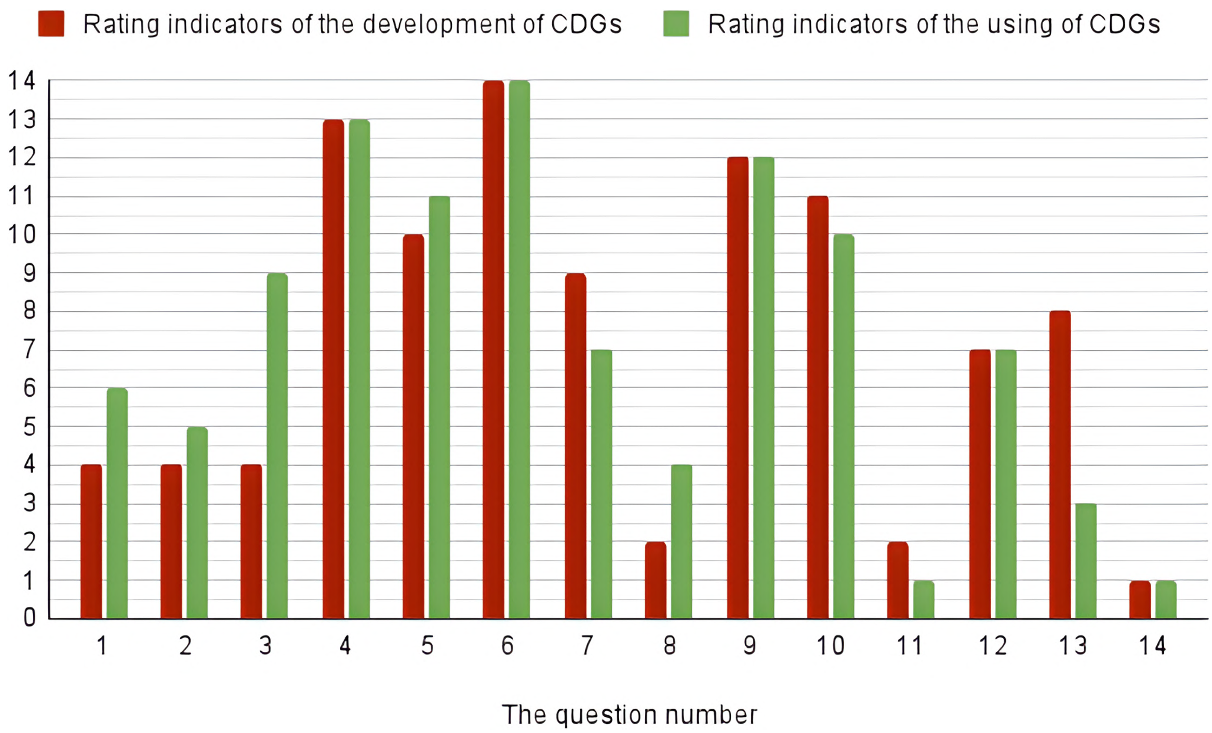

Figure 5: Hierarchy of computer science and mathematics teachers' value orientations as for the development and implementation of CDGs in educational process.

develop students' interest in computer science, to improve teaching skills and strive to self-development and self-improvement aimed at achieving professional success in the acquisition and development corresponding knowledge, abilities and skills in the sphere of CDGs. Additionally, there is a lack of care for material comfort, improvement in social status, recognition in the professional sphere, and achievement of respect. However, computer science and mathematics teachers were also observed to be more oriented towards professional realization and improvement, which dominated their requirement for recognition and respect, improve social status, ensuring material comfort.

The motivation for achievement favours an increase in persistence, self-esteem, regulation of activities, the formation of readiness for the development of CDGs and their implementation into the educational process. The results of the survey of computer science and mathematics teachers show that following the methodology "Diagnostics of motivation for success and fear of failures" [55], 59,2% of teachers have motivation on the average level (the motivational pole is not clearly defined), 21,4% of teachers have a high level of motivation (motivation for success is diagnosed), and 19,4% of teachers have a low one (the motivation of fear of failure is diagnosed) (figure 6). The motivation for achievement activates subjective efforts of computer science and mathematics teachers, directed to the desired outcome in personal and professional development.

According to the results of the study of the motivational-value component of computer science and mathematics teachers' readiness to develop and use CDGs in educational process, in particular, its motivational-value component, we can conclude that 21,4% of teachers are diagnosed with motivation for success and 30,4% of teachers are diagnosed with high level of significance of readiness for the development and implementation of CDGs for successful professional activities.

Figure 7 illustrates the progressive development of key readiness components over the past decade, derived from a synthesis of longitudinal and cross-sectional studies. The consistent upward trend across all components suggests that increased attention to game-based learning in teacher education programs is yielding positive results, though absolute scores remain in the moderate range, indicating substantial room for improvement.

Personality-reflexive component of readiness. This component was considered with the application of research methods of the ability to self-control and reflective potential of the individual. "Questionnaire

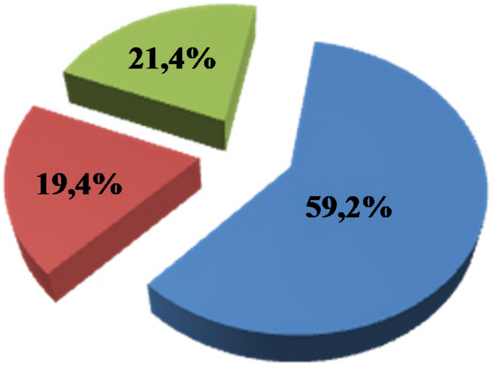

Figure 6: Results of the diagnosis of motivation for success and fear of failure (high level (motivation for success is diagnosed) – 21,4%, average – 59,2% (the motivational pole is not clearly defined), low – 19,4% of teachers (the motivation of fear of failure is diagnosed).) [63].

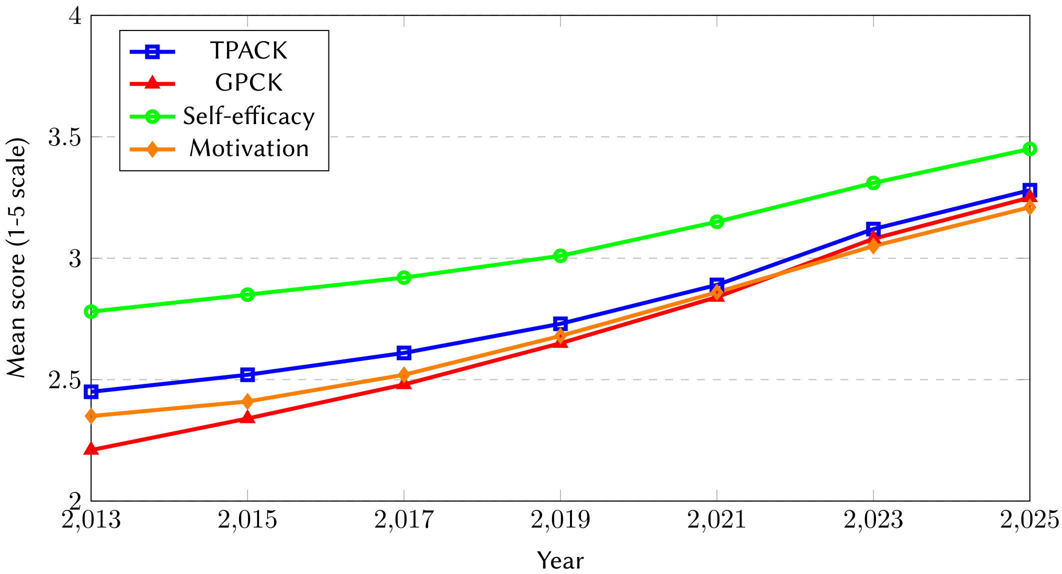

Figure 7: Longitudinal trends in teacher readiness components based on systematic review data (2013-2025). The graph synthesizes findings from multiple studies showing gradual improvement in all components, with self-efficacy consistently showing the highest scores [78, 79, 80].

to determine the percentage distribution of computer science and mathematics teachers by levels of the ability to self-control" [56, 58] and "Questionnaire for determining the indicators of personality-reflexive criterion for evaluation of computer science and mathematics teachers' readiness for CDGs development and implementation" (developed by Klochko [59] based on Rean et al. [55] methods) were used for this purpose. Accordingly, the personality-reflexive component was used, which is characterized by the determination of the teacher's personal style of activities, the awareness of the content of activities, the abilities to evaluate outcomes and consequences, the skills of self-education, self-realization in the professional activities, and life-long learning. The indicators of this criterion are: the ability for self-analysis, self-control, self-organization; the availability of the personal style of activities; understanding the scope of the activities on CDGs developing and implementing; the self-education skills.

The study enabled us to set up the following system-creative factors that determine the ability of computer science and mathematics teachers for self-control: restraint, sense of duty, will power, disciplined manner, and responsibility.

The research results, using the ability to self-control and reflective potential of the individual methods, show that the average values of self-control quality levels of computer science and mathematics teachers were distributed as follows: high level – 39,8%, average level – 51,5%, low level – 8,7% (figure 8) [63]. In our opinion, such results may be explained by job requirements and social context.

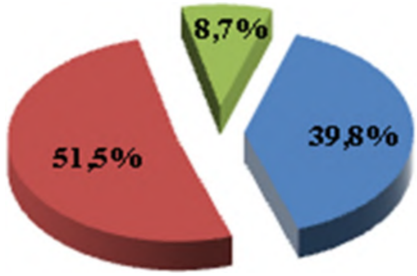

Figure 8: Percentage distribution of computer science and mathematics teachers by levels of the ability to self-control (high level – 39,8%, average – 51,5%, low – 8,7% of teachers).

Hence, as average indicators of the personality-reflexive criterion of computer science and mathematics teachers' readiness to develop and implement CDGs show that the highest rank belongs to teachers' striving for strong performance in this area, for awareness of shortcomings and sincere endeavor to improve performance (diagnosed using the "Questionnaire for determining the Indicators of personality-reflexive criterion for evaluation of computer science and mathematics teachers' readiness for CDGs development and implementation") (table 4, figure 9) [63].

Table 4
Indicators of personality-reflexive criterion for evaluation of computer science and mathematics teachers' readiness for CDGs development and implementation. (The question number column is labeled "№".)

№	In the sphere of CDGs development, ranking	In the sphere of CDGs implementation, ranking
1	7	4
2	5	2
3	6	6
4	1	1
5	2	3
6	4	5
7	3	7

Summarizing the results of the research through their integrative consideration and interpretation within the semantic framework of the personality-reflexive criterion, we note that according to the self-control indicator, most computer science and mathematics teachers are diagnosed with medium and high levels of the ability to self-control. According to the results of diagnosing the indicators of the personal-reflective criterion for assessing the computer science and mathematics teachers' readiness to develop and use CDGs, it can be concluded that teachers mostly want to achieve high results in the areas of developing and using CDGs, know their shortcomings and strive to correct them, try to work in the direction of finding new methods of techniques, forms, ways of implementing CDGs, but to a lesser extent they work on improving acquired competencies in this area.

Cognitive-activity component of readiness. Formation of computer science and mathematics teachers' readiness for the development and implementation of CDGs into the educational process has to be based on practically oriented knowledge and intellectual skills. The indicators of the cognitive-activity criterion, which reflects the content and the technology of development and implementation of CDGs, as well as individual and psychological peculiarities of teachers' readiness, in particular cognitive, are: the field knowledge, the abilities to use the field knowledge for professional purposes and the cognitive activities.

Research according to the cognitive-activity criterion was carried out using the "Questionnaire for determining the indicators of cognitive-activity criterion of evaluation of computer science and mathematics teachers' readiness to develop CDGs and implement them into the educational process"

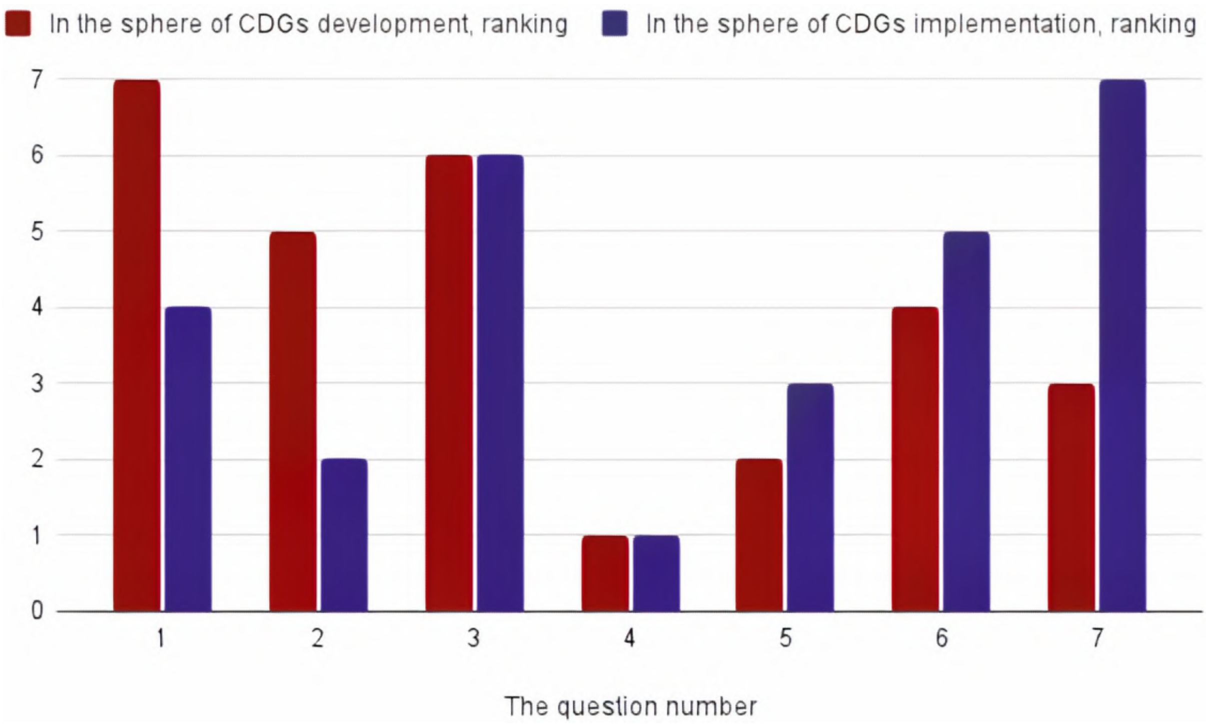

Figure 9: Indicators of personality-reflexive criterion for evaluation of computer science and mathematics teachers' readiness for CDGs development and implementation.

(developed by Klochko [59] based on Raven [62] methods), "Questionnaire to determine the percentage distribution of computer science and mathematics teachers by levels of the ability to self-governance" [56, 57, 58], "Fedorets-Klochko questionnaire for determining the value interpretation of space by computer science and mathematics teachers", as well by the analysis of results of computer science and mathematics teachers' knowledge in CDGs development and implementation theory (the method of monitoring quiz (oral and written) were used). This criterion also reflects the importance of metacognitive strategies, which include the formed abilities for goal setting, self-evaluation, self-management, planning, control, and intellectual reflection. It is significant that the mentioned intellectual qualities should be essentially activity and, accordingly, aimed at the professional sphere of the teacher and, above all, at the development and use of CDGs. Within the framework of this criterion, spatiality is defined as an actual direction of the teacher's intellectual development. The spatial aspect is presented as spatio-cognitive and visual-spatial. Accordingly, within the semantic framework of spatiality, the problematic of the teacher's availability of valuable knowledge, understanding, intellectual intentions and reflections of both real and virtual spaces is actualized [1]. The cognitive-activity criterion for the evaluation of computer science and mathematics teachers' readiness for development and implementation of CDGs characterizes the level of theoretical knowledge, ability to use and create activities that are of significant importance in the professional practice of computer science and mathematics teachers.

The estimation of professional achievements, however, does not fully reflect the level of computer science and mathematics teachers' knowledge in this sphere, as it is a pretty formal indicator of their readiness for the development and implementation of CDGs. The average results of the quiz show that computer science and mathematics teachers' knowledge in theory of CDGs development and implementation is as follows: high – 4,2% and 24,8%; average – 11,2% and 46,5%; low – 84,6% and 28,7% (figure 10, figure 11) [63].

Identifying the indicators of the cognitive-activity criterion, we proceeded from the importance of metacognitive strategies. Accordingly, with formed meta-cognitive strategies the computer science and mathematics teachers understand the process of development and implementation of CDGs as a focused and result-based management of the professional activities and life-long learning that simulates abilities to predict outcomes, plan, control, evaluate, monitor and manage this process, overcome difficulties

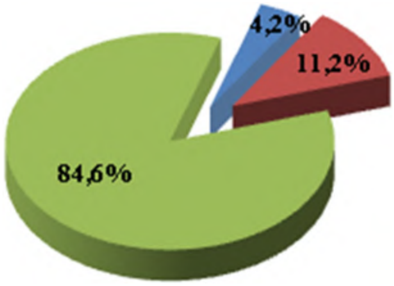

Figure 10: Average results of computer science and mathematics teachers' knowledge in CDGs developing theory (high level – 4,2%, average – 11,2%, low – 86,4% of teachers) [63].

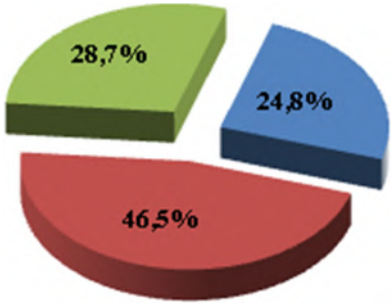

Figure 11: Average results of computer science and mathematics teachers' knowledge in CDGs implementation theory (high level – 24,8%, average – 46,5%, low – 28,7% of teachers) [63].

at the time of achieving tactical and operational purposes as well as strategic goals. We assumed that computer science teachers understand the process of development and implementation of CDGs as a focused and result-based management of the professional activities and life-long learning that simulates abilities to predict outcomes, plan, control, evaluate, monitor and manage this process, overcome difficulties at the time of achieving tactical and operational purposes as well as strategic goals.

So, the results of the tests using the "Questionnaire to determine the percentage distribution of computer science and mathematics teachers by levels of the ability to self-governance" reveal that the computer science and mathematics teachers' ability to self-governance, mainly, is on the average level. The percentage distribution by ability levels is as follows: 35,7% – high, 53,0% – average, 11,3% – low level (figure 12) [63]. These data show that computer science and mathematics teachers according to the self-governance indicator, which to a large extent integratively reflects the formation of metacognitive strategies, are ready to develop and use CDGs in educational process.

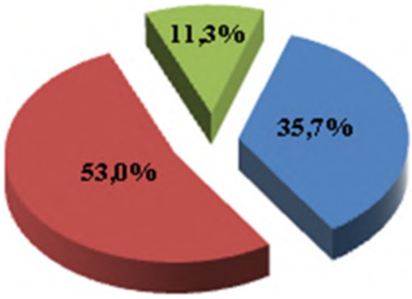

Figure 12: Percentage distribution of computer science and mathematics teachers by levels of the ability to self-governance (high level – 35,7%, average – 53,0%, low – 11,3% of teachers) [63].

The study shows that the formation of the readiness of computer science and mathematics teachers to develop and implement CDGs into the educational process is impossible without the corresponding knowledge and intellectual skills in these spheres, such as: knowledge of CDGs' tools of development and implementation (classification, functional possibilities, didactic peculiarities, development requirements), skills in selection of topics, design development, knowledge of psychological peculiarities of students' age groups, etc. (table 5, figure 13) [63]. The efficient management of this process demands knowledge of problem analysis, a clear vision of the situation, and the ability to forecast and plan future actions.

Table 5
Indicators of cognitive-activity criterion of evaluation of computer science and mathematics teachers' readiness to develop and implement CDGs into the educational process. (The question number column is labeled "№").

№	In the sphere of CDGs development, ranking	In the sphere of CDGs implementation, ranking
1	1	1
2	7	3
3	8	4
4	10	5
5	8	12
6	6	10
7	11	8
8	2	2
9	12	11
10	4	8
11	3	5
12	5	7

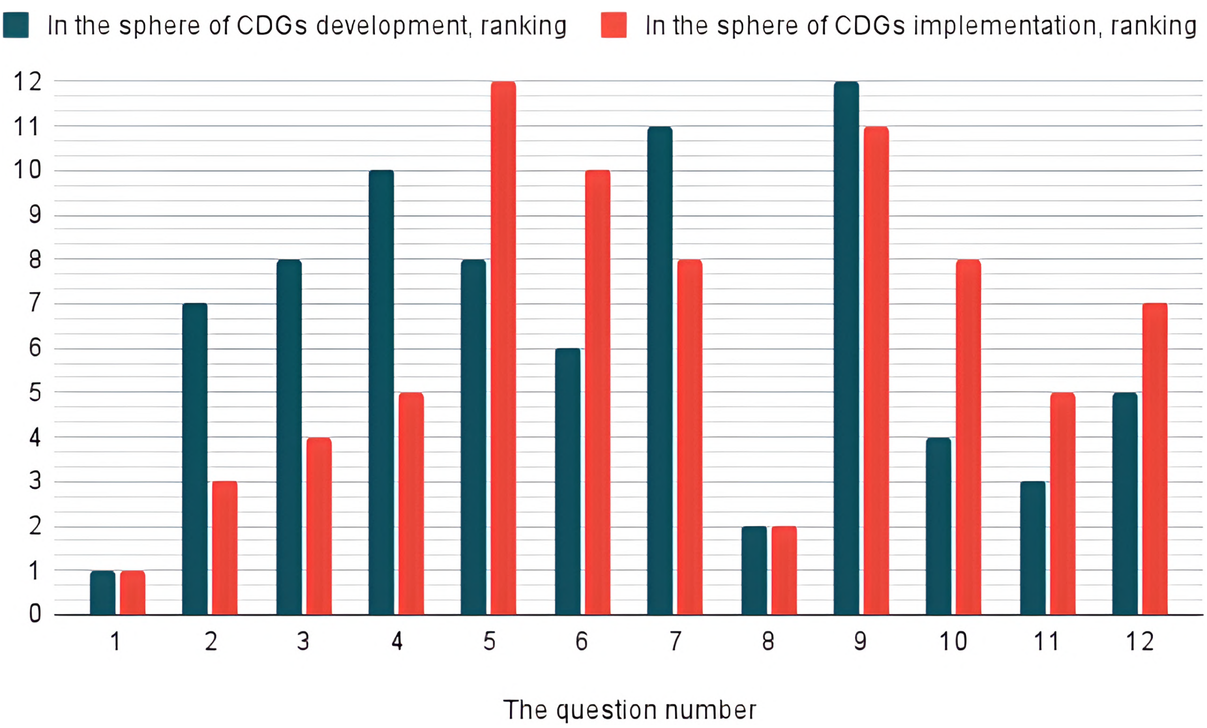

Figure 13: Indicators of cognitive-activity criterion of evaluation of computer science and mathematics teachers' readiness to develop and implement CDGs into the educational process.

Summarizing the results of the research through their integrative consideration and interpretation within the semantic framework of the cognitive-activity criterion, we note that according to the investigated indicators of the cognitive-activity criterion, the majority of respondents are diagnosed with an average and high level of formation indicators of cognitive-activity and self-governance. The average level of theoretical knowledge of computer science and mathematics teachers on the development and use of CDGs in the educational process was also diagnosed, respectively 11,2% and

46,5%, and the high level of theoretical knowledge of computer science and mathematics teachers on the use of CDGs, respectively 4,2% and 24,8%. It should be emphasized that 86,4% of respondents are diagnosed with a low level of theoretical knowledge on the development of CDGs. This may be due to the fact that in the process of training and retraining, professional development of informatics and mathematics teachers, less attention is given to the topic of developing computer games for use in the educational process. The study shows that computer science and mathematics teachers fully understand the process of development and implementation of CDGs, know how to choose games aimed at achieving lesson objectives. They have knowledge, skills and are able to use CDGs in the educational process but have little experience in their development. In their professional activities, computer science and mathematics teachers also face difficulties in understanding the psychological peculiarities of using CDGs by students. Teachers also have to deal with the issue of the definition of the main functionalities of CDGs, since their selection directly influences the realization of the student-centered approach.

During the II stage of the research, which took place in 2022, the value interpretations of space by a mathematics and computer science teacher were studied. This study is considered in the content-semantic framework of the formation of the cognitive-activity component of readiness that was studied. The spatial direction of the research is determined by the fact that the specificity of the development of the cognitive-activity component of readiness is the actualization of the spatial aspect. The spatial aspect is presented in two formats: visual-spatial, which helps to reveal visual-spatial intelligence, and spatial-cognitive, which is aimed at the teacher's use of spatial phenomena (both real and virtual spaces) for purposeful representation and illustration of relevant topics in mathematics and computer science.

Let's consider the results of the questionnaire using the "Fedorets-Klochko questionnaire for determining the value interpretation of space by computer science and mathematics teachers" using the methodological and interpretive potential of cluster analysis. In the process of applying the SimpleKMeans algorithm to the clustering model, built on the basis of a set of data obtained during the questionnaire survey, 4 clusters (number 0, 1, 2, 3) were formed, the centroids of which are shown in the table 6 (figure 14).

Table 6
Model and evaluation of clustering data using the SimpleKMeans algorithm. (The question number column is labeled "№".)

№	Cluster № 0, 53%	Cluster № 1, 23%	Cluster № 2, 13%	Cluster № 3, 13%
1	2	1	1	3
2	3	1	1	3
3	2	2	0	3
4	2	1	0	3
5	2	1	0	3
6	2	0	1	3
7	2	1	2	3
8	2	2	2	3
9	2	1	0	3
10	1	0	3	3

Cluster № 0 is the largest in terms of volume and, accordingly, formed 53% of the responses. The specified cluster unites answers that define space (real and virtual) as a "pedagogical-technological" value that is significant in the process of teaching mathematics and computer science when using didactic computer games (figure 15). This cluster defines the positive interpretation of space in quantitative representation as the middle between negative and highest. Accordingly, a positive understanding of space as an "pedagogical-instrumental" value can be purposefully applied in the educational process. Cluster 0 dominates in the specified sample is half. This dominance indicates that the studied teachers, who make up half of the sample, have a generally positive attitude towards this problem. At the same time, the indicated "middle position" in the sample indicates a not maximum readiness to actualize the spatial component when using didactic computer games. The not-total "fascination" with visual-spatial issues also indicates the critical thinking and personal and intellectual maturity of teachers, because the

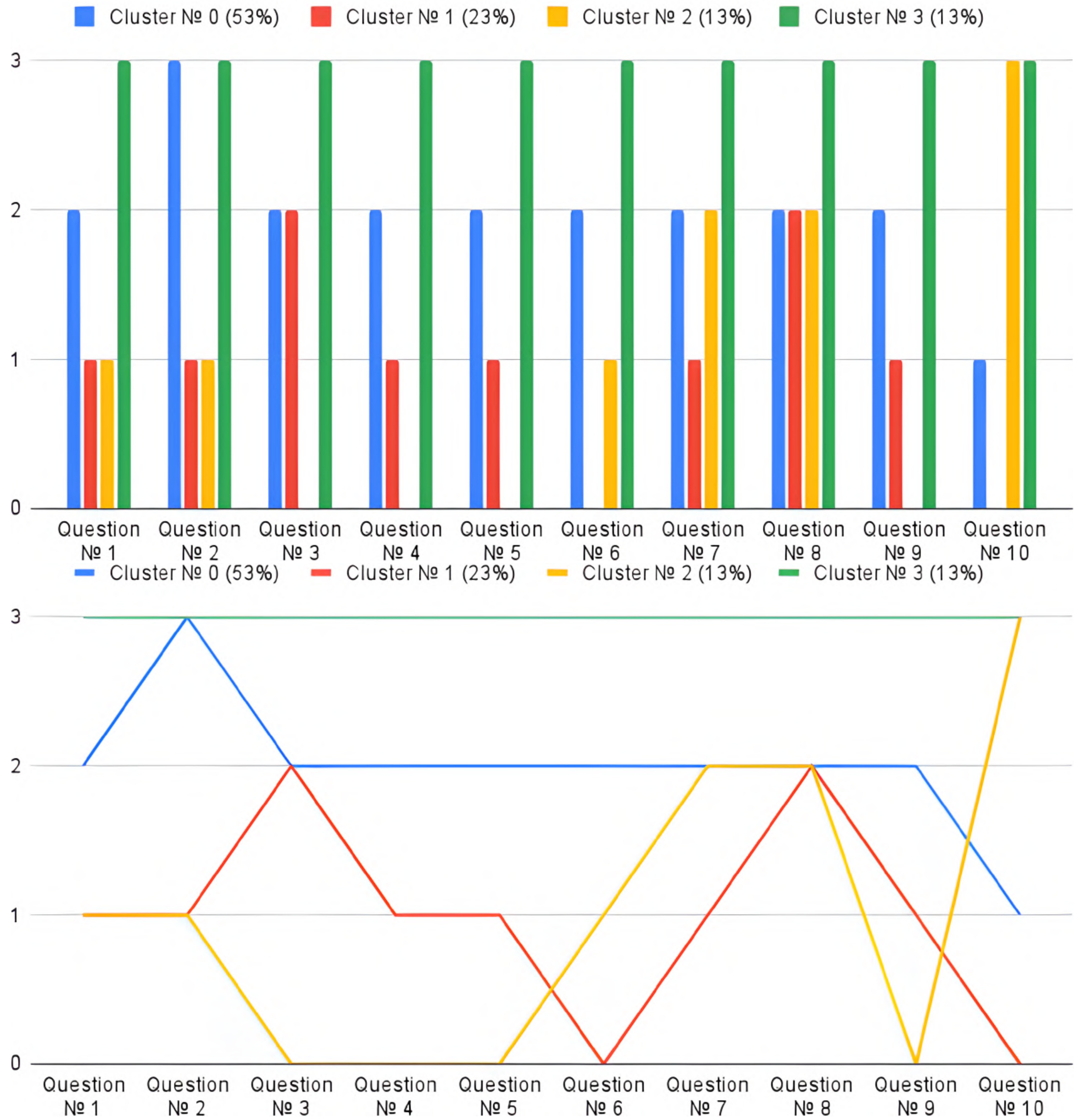

Figure 14: The centroid values of the clusters according to the question number of the "Fedorets-Klochko questionnaire for determining the value interpretation of space by computer science and mathematics teachers" are presented in a bar and linear charts.

representation of space as an instrumental value is relatively new and for many teachers it was revealed through their questionnaires. As mentioned above, the purpose of the survey was not only diagnosis, but also actualization of the phenomenology of space as value-oriented and technologically oriented. The trends of Europeanization, democratization and humanization of Ukrainian education defined in the Concept of the New Ukrainian School [81] play a certain role in such a dominant, but at the same time, "moderate" or "medium" distribution. The specified educational trends contribute to the professional development of the teacher. Accordingly, the teacher develops as a competent, critical-thinking and independent person who finds and forms "his" teaching methodology and methods.

Clusters № 1 (23%) and Clusters № 2 (13%) (total 36%) include answers that represent space (real and virtual) as a "pedagogical-technological" value that is considered significant, neutral or negative in the context of teaching mathematics and computer science when using didactic computers computer games. Accordingly, the answers can be presented as a continuum from negative to positive – 0, 1, 2

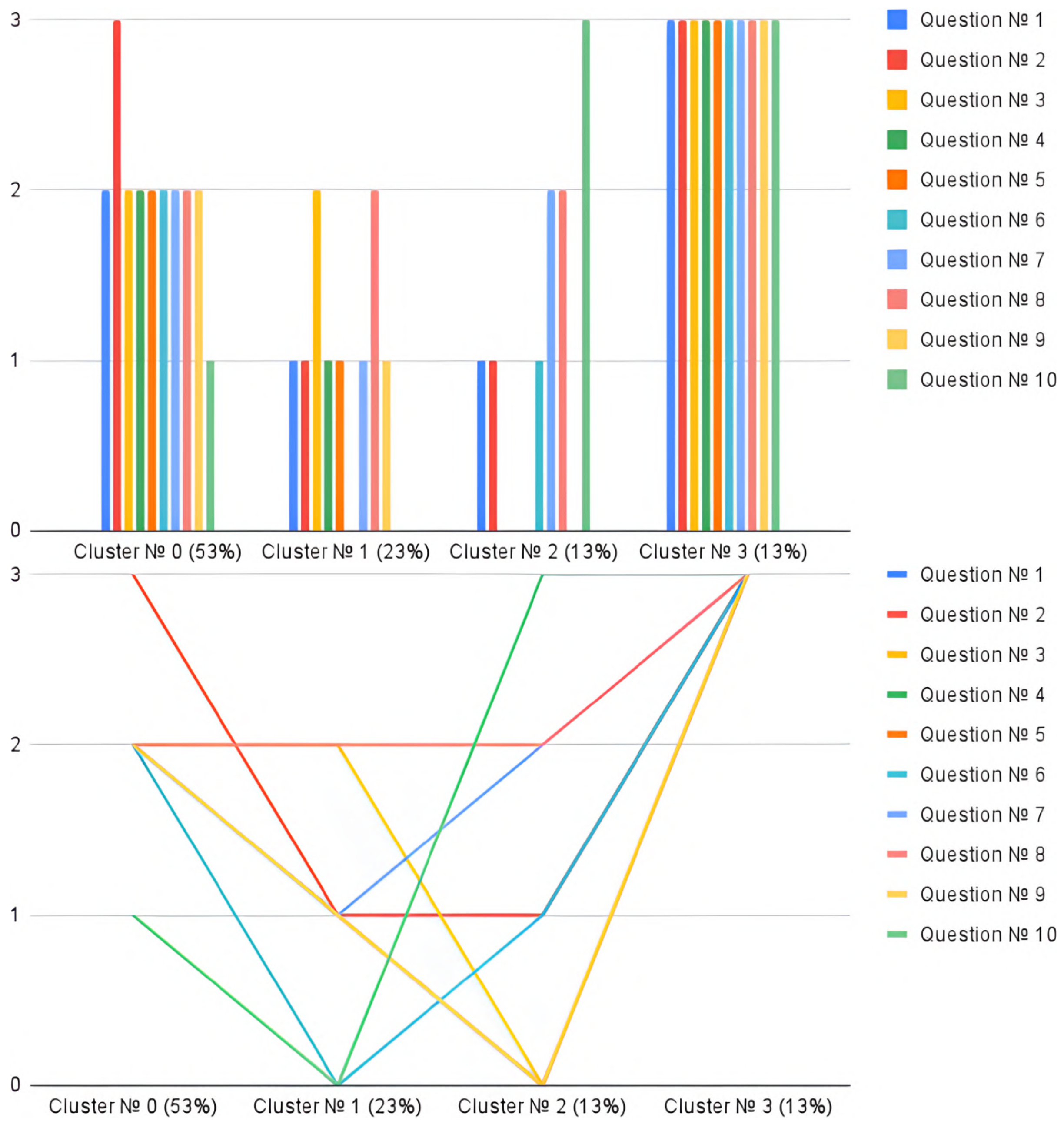

Figure 15: The centroid values of the clusters according to the cluster number of the "Fedorets-Klochko questionnaire for determining the value interpretation of space by computer science and mathematics teachers" are presented in a bar and linear chart.

and 3 (one answer). The presence of cluster № 1 and cluster № 2 (total 36%), which are quite significant in terms of volume, which makes up more than a third, speaks of a certain novelty and possible certain incomprehensibility of the actualized issues, which are represented in general terms, and not as a specific technology. It is clear that at this stage the specified "visual-spatial approach" is first of all revealed at the level of methodology in the form of general ideas and interpretations.

Cluster № 3, which is represented by 13% of respondents' answers, represents the highest level of teachers' interpretation of space (real and virtual) as a technological value that is significant in the process of teaching mathematics and computer science when using didactic computer games. We explain the relatively small percentage of people who, at the highest level, interpret space (real and virtual) in a value-oriented way, considering it as a probable component of the implementation of computer didactic games, by the relative novelty of such a spatial approach, the complexity and non-traditionality of its implementation (figure 15). In this aspect, it can be noted that the emergence of virtual space as a digital technology, as a specific "anthropo-techno-cultural" phenomenon and the actualization of game-based learning methods provides an opportunity to better understand the educational significance of the cognitive-valuable potential of real space. In general, we observe a "shift" in pedagogy towards the active use of environmental, contextual, "background" approaches to learning. Accordingly, the environment, including space and time, is understood not only as a background for the educational process, but also as a special meaningful and value-semantic aspect of learning or, even, a "visual-spatial educational tool".

Having analyzed the structure of the distribution of answers by clusters, it can be noted that it reflects the indicated trends of the emergence and active development of contextual approaches (including visual-spatial) in education and the active use of digital technologies.

Summarizing and interpreting the results of the research of the spatial aspect in the system of the cognitive-activity component of the studied readiness, we can note that they reveal the relevance and significance of this "visual-spatial-cognitive" direction of the development of the specified readiness, first of all from a practical and pedagogical point of view. It is important that many teachers understand the phenomenology of real and virtual space as a significant pedagogical tool that corresponds to the current modern ideas of spatial pedagogy, existential pedagogy, child-centeredness, and contextual learning.

We can say that we are witnessing the beginning of an active integrative application of digital, spatial, game, axiological methods and technologies, which corresponds to the paradigmatic attitudes of postmodernism, including the officially defined direction of sustainable development, which pays special attention to the "terrestrial space" and the person in it.

4. Conclusions

The readiness of computer science and mathematics teachers to develop and use CDGs in the educational process is a complex integrative personality-professional formation, consisting of motivational-value, cognitive-activity and personality-reflexive components, which specified in their corresponding criteria.

By the computer science and mathematics teachers' readiness to develop and use CDGs, we understand the integrated cognitive-activity professionalpersonal ability of the teacher, which contains expressive value-motivational and reflective components and is aimed at implementing CDGs into the educational process, and is also implemented on the basis of modern directions – innovative development, humanism, child-centrism, creativity, communicativeness, and taking into account spatial-temporal and cultural-educational specifics.

Determining the state of formation of the motivational-value component of readiness, we can indicate that according to the indicator of motivation for success in professional activity, 59,2% of teachers have an average level of motivation (the motivational pole is not clearly defined), 21,4% of teachers have a high level of motivation (success motivation is diagnosed), and 19,4% of teachers have a low level (diagnosed lack of success motivation). According to the indicator of the value of readiness for the development and implementation of CDGs for successful professional activity, the following levels were determined: 30,4% – high, 50,1% – medium, 19,5% – low. There is a certain correlation between the above indicators, which indicates both the formation of the motivational and value sphere and its professional orientation, as well as its focus on the application of CDGs. The following value orientations in the field of development and use of CDGs in the educational process were also determined to be significant for teachers: "Possibilities of introducing new methods and forms of working with students", which indicates developed innovativeness; "Development of students' interest in studying informatics", which indicates the child-centered orientation of teachers. Thus, analyzing and interpreting the values of the above indicators, we can note that according to the motivational-value criterion, an average level of formation of the motivational-value component of readiness is observed in most teachers.

According to the cognitive-activity component of readiness according to the indicator of the ability to self-governance, which reflects the formation of metacognitive abilities, which includes goal setting, self-esteem, self-management, planning, control, intellectual reflection, the obtained percentage distribution of its formation is 35,7% – high, 53,0% – medium, 11,3% – low in terms of levels. The presence of the prevailing high and medium levels indicates a sufficiently high initial level of formation of metacognitive abilities, which are included both in the composition of the studied readiness and in the professional and pedagogical competences of a computer science and mathematics teacher. The average level of theoretical knowledge of informatics and mathematics teachers regarding the development and use of CDGs in the educational process was diagnosed: average – 11,2% and 46,5%; high – 4,2% and 24,8%; low – 86,4% and 28,7%. Having analyzed the relevant training programs, we believe that the reason for such a state of the level of theoretical knowledge is insufficient training in the indicated direction, both during university studies and during advanced training in the conditions of postgraduate education. The state of formation of the cognitive-activity component of the readiness of computer science and mathematics teachers for the development and implementation of CDGs according to the spatial indicator, according to the results of the cluster analysis, professional interest was determined in 53% of teachers, in 13% – a formed positive attitude is present, in 36% – insignificant interest or negative attitude. We explain the small percentage of respondents who, at the highest level, interpret space (real and virtual) in a value-oriented way, considering it as a probable spatial-cognitive component of the implementation of CDGs, by the relative novelty of such a spatial approach, the complexity and unconventionality of its implementation. During the integrative examination of indicators of the formation of the motivational-value component in the semantic framework of its (motivational-value) criterion, its average level of formation is determined.

The state of formation of the personal-reflective component of computer science and mathematics teachers' readiness to develop and use CDGs according to the indicator of the ability to self-control is characterized by the following percentage distribution – high level – 39.8%, medium level – 51,5%, low level – 8,7%. Predominance of medium and high levels of self-control formation as a quality significant for the teacher's professional activity, including the implementation of developed professional mathematical and informational competencies. According to the personal-reflexive indicator, the vast majority of teachers are diagnosed with the desire to achieve high results, knowledge of their shortcomings and the desire to correct them, which indicates purposefulness, the presence of professionally directed reflection and innovative orientation. During the integrative examination of indicators of the formation of the personal-reflexive component in the semantic framework of its (personal-reflexive) criterion, the average level of its formation is determined.

Summarizing the results of the research based on consideration of motivational-value, cognitive-active and personal-reflective criteria, we can say about the diagnosis of the average level of computer science and mathematics teachers' readiness to develop and use CDGs. Based on this, we define the following main strategies for its improvement: supplementing educational programs with topics that represent the ways and practices of applying CDGs in the preparation of future computer science and mathematics teachers, their retraining and advanced training; application of competency-based, activity-based approaches in order to develop teachers' professional orientation to the application of CDGs; to activate the use of innovative pedagogical technologies for the formation of computer science and mathematics teachers' readiness to develop and use CDGs; to carry out an analysis of the application of CDGs in other countries and the reception of positive pedagogical experience in this direction.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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