



DOI 10.22363/2313-1683-2021-18-1-140-152

UDC 377.018.48

Theoretical article

## Scientific and Methodological Support for Teachers in the Context of Gamification in Mathematics Study in the Russian System of Additional Education

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**Abstract.** The relevance of this study is due to the practical significance of the issues of using game mechanisms in the process of teaching mathematics, the lack of research into the issues of symbiosis of game and didactic technologies in mastering complex mathematical knowledge, the need to search for effective technologies to establish how they affect the development of students and the formation of a modern style of thinking. The analysis of global trends and practices of introducing elements of gamification into the education system has shown that the mastering of complex knowledge and patterns of mathematical activity, the solution of “problem areas” of mathematics at different levels of learning and complexity is carried out by a complex of mathematical and information methods without the integration of game elements. It has been substantiated that gaming technologies in combination with the informatization of mathematical activity give a powerful motivational charge to the study of mathematics, actualize the processes of self-organization of cognitive activity, and contribute to the development of a probabilistic style of thinking. The purpose of the study is to provide a theoretical substantiation and effective methodological support for the process of professional development of mathematics teachers in the context of gamification in mathematics study with the effect of developing a probabilistic style of thinking. The authors have developed an arrangement mechanism and determined the content of scientific and methodological support for teachers working in the constituent entities of the Russian Federation to provide additional educational services in the context of gamification in education. The developed materials, in particular, include evaluative case tests for identifying competence deficiencies in teachers, which ensure the formation of a probabilistic style of thinking based on gamification processes by managing the information saturation of the motivational field of learning. In addition, the authors proposed an additional professional education program for teachers, *Mathematics in Gaming Activities (Business, Didactic and Intellectual Games)*, and developed new forms of certification and assessment materials (gamification-based didactic solutions and effective practices). Using the concept of ‘gamification’, it was possible to demonstrate the activation of cognitive and motivational structures, in particular, the effective development of a probabilistic style of thinking in the process of mastering complex mathematical

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knowledge through its adaptation to school mathematics. The results of the study allow making it possible to bring the process of teaching students and developing their personalities to a modern qualitative level using current achievements in the field of digitalized education.

**Key words:** mathematics study, additional education, gamification, probabilistic style of thinking

**Acknowledgements and Funding.** This study was funded by the Russian Foundation for Basic Research under Research Project No. 18-313-20002.

## Introduction

In the last decade, a new educational technology – gamification, which in science is understood as the use of game methods in a non-game environment, in particular in teaching, – has acquired particular relevance. The entire history of education convincingly demonstrates the effectiveness of this technology. A huge number of psychologists, teachers, mathematicians, and methodologists have devoted their fundamental works to the game as a scientific category. Scientific theories of the game have been the subject of systematic scientific study from various positions, such as: physiological (Cowley et al., 2014; Guillén-Nieto, Aleson-Carbonell, 2012; Nacke et al., 2010 and others); biogenetic (G.S. Hall, L.E. Appleton and others); social (Groos, 2009 and others); biopsychological (W. McDougall, G. Murphy, F.J. Bentendijk); sociological (K. Rainwater, D. Rismen, M. and E. Neymer); psychotherapeutic (S. Freud, Ya. Moreno, G. Lehmann); cultural (J. Heising); pedagogical-psychological (Elkonin, 1989; Piaget, 1985; Vygotsky, 1996), and didactic (Pidkasisty, Khaidarov, 1996; Shabalina, 2013; Utesch, 2016; and others). Mathematical optimal game strategy methods are studied in game theory and find many applications in economics, management, marketing, sociology, psychology, conflict resolution studies and other sciences. The need to combine motivational-value, emotional-volitional, social, cognitive, research and personal behavioral strategies in the process of gaming activity into a single integrity creates a precedent for expanding and deepening the experience of an individual, forming and developing metasubject, subject and professional student competences.

Full involvement in physical training and sports for both children and adults, professionally oriented gaming activities (business games, game design, educational games, case technologies, web quests, etc.), didactic games, intellectual gaming activities (checkers, chess, Go, Renju, Zhipto) really have a positive effect on the cognitive, social, creative and professional personal development. For instance, a number of researchers (Sala, Gobet, 2016, 2017; Burján, 2016; Singley, Anderson, 1989; Frydman, Lynn, 1992) argue that teaching intellectual games improves the math ability of elementary and middle school students. A significant influence of intellectual games on the development of a wide range of cognitive abilities, such as attention and concentration, planning and memory, logical thinking and spatial imagination, has been empirically established. The authors consider teaching chess to be an effective educational tool that has a positive cognitive effect on children's mastering math, both in the short and long term. However, a new study (Sala et al., 2017) seriously challenges the 'chess effect' hypothesis in teaching mathematics. Also S. Hong and W. Bart, examining students aged 8–12 with

weak abilities (close to failing), came to the conclusion that chess education does not play any role in cognitive development (Hong, Bart, 2007; Bart, 2014).

According to other international researchers (Burgoyne et al., 2016), chess is a complex and creative intellectual activity. The scientists obtained an unexpected result: the positive correlation between cognitive abilities and the ability to play chess in children and adults is more pronounced at low levels of chess skills than at higher ones. Therefore, according to Russian and international psychologists and teachers, the introduction of chess into school math course enhances the development of cognitive abilities, increases educational motivation and the quality of acquired math knowledge and skills, and also provides a synergistic effect in acquiring complex mathematical knowledge along with personal self-development and creative autonomy.

Some authors (Karapetyan et al., 2016; Karapetyan, Gevorgyan, 2017) show the relationship between the determination of the appropriate choice of chess moves and typical manifestations of cognitive dissonance and consonance that naturally arise in the process of argumentation. The psychological phenomenon of cognitive dissonance and consonance in the field of argumentation during the game of chess is transformed into appropriate orientation situations. The results of emotional-logical comparison with logical and internal conflicts are considered. This is evidenced by the subsequent choice, adequately or inadequately expressed in the emotional and behavioral manifestations of the players.

The undeniable effectiveness of game pedagogy in the formation of creative activity, in the development of the motivational sphere has stimulated numerous research projects around the world (Bi, 2013; Guillén-Nieto, Aleson-Carbonell, 2012; Ersoy, 2014; Michel, 2016; Pound, 2017). An effective means of stimulating creativity is the solution to creative problems, which is carried out by choosing one of the two ways:

(1) the use of a logical type of thinking by separating the essential properties of phenomena from insignificant, necessary from random, general from particular ones. The logical type of thinking assumes the correctness of each step, which leads to the correct final result;

(2) the application of intuitive thinking based on vague data without prior logical reasoning. In this case, the solution to the problem is minimized in time, and the solution process is implemented to a minimum.

Researchers (Al-Sabaty, Davis, 1989) found that changing the stereotypical style of thinking can significantly increase the creativity of students who approached creative problems in the first way, focused on the second way, and vice versa. The authors have substantiated and practically confirmed this thesis. For instance, S.N. Dvoryatkina (Dvoryatkina, Shcherbatykh, 2019) presents a draft technology for integrative teaching of mathematics based on solving problems on a chessboard with the actualization of the creative effect. The proposed complex of multi-stage mathematical problems on a chessboard allows students to master not only mathematical methods (combinatorial, probabilistic, graph theory, set theory, mathematical and computer modeling) but also contribute to the development of creativity.

But that was all before. What are the key factors behind the need for gamification in education?

First, the gamification in education is the continuity of the formation of intellectual operations of thinking in the process of game practice as an element of non-formal education. In particular, intellectual games (e. g., chess, checkers) provide a unique opportunity to involve intellectual operations in the process of analyzing positions, comparing and highlighting situations, evaluating the current state of a position, predicting the upcoming course, developing situational activity and visual modeling both in formal and non-formal education.

In the context of digital transformation of education, there is a need for the formation of new key competences, which include the abilities to generate original ideas, search for new information, make a critical analysis and synthesis of it, apply a systematic approach to solving tasks, show flexibility, criticality, creative activity in solving tasks, use interdisciplinary knowledge in situations of uncertainty and increasing diversity or actions of random factors, that is, to possess a probabilistic style of thinking.

The process of developing probabilistic thinking is determined by quantitative changes in its structure, the composition of cognitive substructures, the number and order of connections between them, as well as the qualitative enrichment of intellectual operations of mental activity, such as analysis, synthesis, evaluation and forecasting (Dvoryatkina, 2013). This conclusion allows us to suggest that it is possible to effectively develop probabilistic thinking in students based on gamification processes. At the same time, computer learning increases the developmental effect.

Second, it is a unique opportunity to integrate mathematical and informational knowledge against the background of a motivational-educational space for students. Mathematical puzzles around the chessboard, combinatorics and probabilistic position estimates, geometric shapes and transformations in the dynamics of positional analysis, numerical characteristics and problems of measuring lengths and areas contribute to creative activity, the development of students' reflexive abilities. Checkers and chess provide a huge field of activity for students in the process of mastering programming strategies and tactics, mathematical methods for estimating positions, and selecting algorithmic languages. The development of computer versions of Go, Renju and GIPto (Intellectual Game – Pursuit) games is a separate interdisciplinary task that requires serious mathematical and information knowledge.

A fundamental analysis of global trends and practices of introducing gamification elements in the education system makes it possible to establish a fairly active practical implementation of game technologies in the humanities (foreign language, economics, management, etc.) and computer science. In the process of developing complex constructs and patterns of mathematical activity, the solution of 'problem areas' of mathematics at different levels of learning and complexity is carried out by a complex of mathematical and information methods without the integration of game elements. However, many researchers (Callaghan, 2017; Dvoryatkina et al., 2019; Gik, 2010; Ignatov, 2018; Poloudin, 2017; Sala, Gobet, 2016; Sukhin, 2012; Poloudin, 2017; Zirawaga et al., 2017) note that game technologies in combination with computerization of mathematical activity give a powerful motivational charge to the mathematics study, actualize the processes of

self-organization of students' cognitive activity and contribute to the development of probabilistic thinking.

At the same time, with all the relevance of and demand for gamification in education, including the possibility of applying its principles for modernizing the system of mathematics study in the context of the introduction of digital technologies, there are several contradictions:

- the requirement for the organization of the educational process using game technologies and insufficient qualification of the majority of mathematics teachers for the practical implementation of technological gamification;

- the need to improve the quality of continuous pedagogical education in the context of digitalization of mathematics study and the lack of development of the system of scientific and methodological support for teachers to provide additional educational services in the context of the introduction of new game mechanics to improve the quality of mathematics study.

All of the above, as well as the need to resolve the identified contradictions, allow us to formulate *the research problem*: what is the content of scientific and methodological support for teachers to provide additional educational services in the context of gamification in mathematics study in the process of adapting modern scientific achievements for effective teaching of mathematics at school?

*The purpose of the study* is to provide a theoretical substantiation and effective methodological support for the process of professional development of mathematics teachers in the context of gamification in mathematics study with the effect of developing a probabilistic style of thinking.

### **Didactic mechanism for organizing scientific and methodological support for teachers of mathematics**

Training and retraining of teachers to effectively solve pedagogical problems of mathematics study requires an innovative approach. This approach in our study is the Project to create a scientific and methodological center for supporting teachers on the basis of higher education institutions.

The purpose of this Project is to develop mechanisms for organizing and determining the content of scientific and methodological support for teachers to provide additional educational services in the context of gamification in mathematics study with the effect of developing a probabilistic style of thinking.

This innovative Project includes:

- conducting research to identify professional competence deficiencies of teaching staff;

- establishing departments for methodological initiatives, support and consulting of the development team;

- conducting specialized scientific research;

- developing and implementing programs of additional professional education;

- developing didactic solutions in the context of gamification in education and effective practices based on them.

Let us briefly describe each of these organizational measures.

## **Pedagogical research to identify teachers' professional competence deficiencies**

Homing and searching experiments to identify teachers' professional competence deficiencies in the context of the scope of methodological knowledge, competence and pedagogical experience of working with complex mathematical knowledge in the organization and management of educational and gaming activities were organized on the basis of five regions of Russia. The following methodological competences were formulated:

– *readiness to adapt and use knowledge of modern problems of mathematical science in solving practice-oriented tasks with the effect of developing a probabilistic style of thinking in educational and gaming activities (methodological competence, MC-1);*

– *the ability to form a rich information and educational game environment by means of mathematical and computer modeling when solving practice-oriented tasks in order to develop probabilistic thinking in students (MC-2).*

The case method was used as assessment material for measuring the level of teachers' proficiency in methodological competencies in the field of working with complex mathematical knowledge in the organization and management of educational and gaming activities. The case test *Studying Gamification as a Tool for Mastering Complex Knowledge* included: a preamble; a unit of tasks consisting of six questions with one answer to be selected from several options; a case assessment sheet reflecting the assessed competences and the answer option with points (three-level assessment: reproductive, productive, reflexive); and comments for the user. The validity of the case tests was ensured by the representative and homogeneous sample, the theoretically substantiated possibility of measuring competences using a certain method, and the degree of representation of the methodology of the content of the measured area of properties in the tasks. Below is an example of an assessment task for diagnosing the formation of MC-2.

The innovative approach to selecting the content of mathematics study at school in accordance with the tasks of developing students' mathematical literacy and probabilistic style of thinking in the context of modernization is based on the acquisition of complex knowledge with the manifestation of synergetic effects. The innovations are based on the methodology and implementation of the concept of game activity and the manifestation of synergy of mathematics study at school in the context of personal self-organization. The human history clearly demonstrates the effectiveness of the formation and development of human functional capabilities during the game.

*What, in your opinion, are the main reasons and factors for the inclusion of gaming in mathematics education? (choose only one answer)*

a) *the implementation of contextual learning (the main aspect of planning and analyzing tasks in PISA, which is closely related to the formation of mathematical literacy and nonlinear thinking) is most effectively implemented only through gaming activities;*

b) *a unique opportunity for synergy of mathematical and digital literacy against the background of intellectual formation, development of probabilistic style of thinking, which have a real positive impact on the students' physical, social, creative and pre-professional development;*

c) *the continuous formation of intellectual operations of thinking and fundamental mathematical abilities in the process of game practice as a key element of mathematics study;*

d) *visibility and accessibility in the development of complex knowledge in four categories: space and form, change and dependencies, quantity, uncertainty and data.*

The preliminary research results showed a low and medium level of methodological competences among school teachers. In particular, 59% of the respondents had a low level of methodological competence in the field of organizing the educational process using game mechanisms in the acquisition of complex knowledge, whereas 32% had a medium level; 79% showed a willingness to increase it.

### **Structure and content of the additional professional development program**

Each of the six regions of the Russian Federation (Kostroma, Vologda, Lipetsk, Nizhny Novgorod, Ivanovo and Yaroslavl regions) has a department of methodological initiatives '*on new didactics of mathematical education: adaptation of modern scientific achievements and gaming activities to teaching mathematics at school*'. These departments are responsible for scaling up initiatives on regional and interregional platforms by organizing training events (seminars, workshops, webinars), testing and implementing initiatives by selecting and describing effective pedagogical practices, methods, technologies and didactic solutions for further broadcasting within the framework of scientific and methodological support for teachers and their training in additional professional programs. In line with the main direction, three methodological initiatives were developed that correlate with the main directions of the center's work. Lipetsk region implements the direction on the topic *Strategy and Tactics in Intellectual Games: Elements of Mathematical Modeling*.

Technologically, a new form of ensuring effective methodological support for teachers of mathematics with the effect of developing a probabilistic style of thinking based on modern achievements in science is the program *Mathematics in Gaming (Business, Didactic and Intellectual Games)* developed by the authors. The program is designed for teachers to improve their existing and acquire additional competences in the field of modern didactics and methods for teaching mathematics by identifying the potential for synergy of mathematical and gaming activities (business, didactic and intellectual games). The main objectives are (1) to reveal to teachers of mathematics a wider range of possibilities for introducing gamification elements into the education system in general and managing the learning process in mathematics in particular; (2) to apply forms and methods of organizing a motivational-educational space through immersion in the game space (including virtual); (3) to provide scientific and pedagogical support for managing the implementation of creative abilities and functional capabilities of students in the process of their acquisition of multi-level complex mathematical knowledge; and (4) to identify and assess the synergetic effects of this form of education.

The optimal structure of the program of continuing education courses was determined, represented by the following modules.

1. *Methodological approaches and psychological and pedagogical theories of designing an integrative educational and gaming space.* The role of personality-oriented, context-vector, behavioral, neurophysiological, environmental and synergetic approaches in building a model of gamification in mathematics study in the context of the symbiosis of scientific, technocratic and humanitarian paradigms. Didactic achievements in the study of the meaning and essence of gaming technologies in education. Psychological analysis of the game. Pedagogical possibilities of didactic and intellectual games. Developing a probabilistic style of thinking when integrating mathematical and gaming activities.

2. *Gamification in modern mathematics study: content and technological aspect.* Active and interactive technologies for teaching mathematics, focused on the development of a probabilistic style of thinking: classification, principles of preparation and organization, methodological features of conducting training sessions, implementation practice (web quests, business games, game design, didactic games); technologies for teaching mathematics based on solving problems on a chessboard; video games in teaching: classification of video games and game mechanics; possibilities of using game mechanics in the educational environment; list of services and communities that use gamification in mathematics study (Motion Math Games, Mathletics, World of Classcraft, Academy of igropractics, live games, etc.).

3. *Strategy and tactics in intellectual games: professional and practical module.* Students' reports on the implementation of game technologies in the practice of teaching mathematics. Suggested topics of reports: Technology for identifying and correcting 'problem areas' in teaching mathematics based on a chess game (e.g., any section of the school mathematics course); Developing creative thinking when solving mathematical problems on a chessboard; Modeling educational activities using didactic games in math lessons; Forming functional literacy through didactic games in math lessons; Business game in mathematics as a way of forming financial literacy of schoolchildren; Gamification in mathematical activity as a factor of increasing educational motivation of schoolchildren, etc.

### **Didactic solutions and effective practices in the context of gamification**

The participants were also provided with new forms of certification and assessment materials. In particular, as part of the project, the authors developed didactic solutions in the context of gamification, including a brief theory on the research problem and its technological solution. The description of the technological solution included: the stages of application, the step-by-step activity of the teacher and the activities of students, the educational result at each stage, the advantages of this technology and its limitations as well as a list of sources on domestic and foreign experience in using a particular technology. Here are examples of the topics for didactic solutions: Business game as a form of designing practice-oriented solutions in financial mathematics, Dialog of cultures in gaming activities as a way of acquiring complex mathematical knowledge, Mathematical foundations of intellectual games, Developing a probabilistic style of thinking in solving mathematical problems on a chessboard, Technology for identifying and correcting 'problem areas' in teaching mathematics based on chess games, etc.

Taking the proposed didactic solutions as a basis, the teachers developed their own effective practices for developing a probabilistic style of thinking in school students based on gamification. These were a series of lesson scenarios with the introduction of game mechanics, a cycle of laboratory and calculation classes, elective course programs for school students, didactic games, web quests, summaries of resource classes or a fragment of a lesson using game technologies, etc. The following best practices were presented:

- draft elective course *Methods for Organizing Resource Classes as a Means of Developing a Probabilistic Style of Thinking in Students based on Gamification*;
- draft elective course *Mathematical Modeling in Intellectual Games*;
- a series of laboratory and calculation classes on the topic *Decision-Making based on Statistical Data Analysis*;
- case assignment on the topic *Methods of Decision-Making Using Descriptive Statistics Methods*;
- didactic game on the topic *Random Events*;
- scenario of the didactic game on financial literacy *Firm of the Year*;
- quest game *The Bank and Me*, etc.

### **Conclusion**

The study has shown the importance and possibility of integrating game tools into the system of mathematics study in the process of training future teachers of mathematics. The results of using the concept of *gamification* demonstrate the activation of cognitive and motivational structures, in particular, the effective development of a probabilistic style of thinking in the process of acquiring complex mathematical knowledge through its adaptation to school mathematics.

The project on *Creation of Scientific and Methodological Teacher Support Centers on the Basis of Higher Education Institutions* is presented. The conceptual basis for the content of scientific and methodological support for teachers to provide additional educational services in the field of mathematics study was the idea of gamification in education in the context of adapting modern achievements in science to school mathematics with the effect of developing nonlinear and probabilistic thinking.

As part of the project, an ascertaining experiment was conducted to identify professional deficiencies of teaching staff in terms of the breadth of methodological knowledge and experience in working with complex mathematical knowledge in the organization and management of educational and gaming activities. The study was organized on the basis of five regions of Russia; the respondents were teachers of mathematics aged 22–40 years. Methodological competences were formulated that determine the readiness and ability to effectively solve methodological problems in the process of implementing the learning goals. To assess the level of formation of methodological competences, the authors' methodology was used – a case test 'Studying gamification as a tool for mastering complex knowledge'. The study revealed a low (59%) and medium (32%) levels of methodological competence in the organization of the educational process using game mechanisms in the acquisition of complex knowledge as well as the readiness of a large number of the participants (more than 79%) to improve it.

Based on the results of identifying professional deficiencies, the program *Mathematics in Gaming (Business, Didactic and Intellectual Games)* was developed for different formats of its implementation (full-time and distance), and the optimal modular structure of the course was determined. The content of the program is filled with methodological approaches and psychological-pedagogical theories of constructing an integrative educational and game space, the synergy of game and didactic technologies for teaching mathematics with the effect of developing a modern style of thinking and, as a result, increasing the professional level of a 21<sup>st</sup> century teacher. The effective practices prepared by the students on the basis of gamification (programs of elective courses for school-children, didactic games, web quests, summaries of resource classes or lesson fragments using game technologies, etc.) established the formation of methodological competences in the organization and management of educational and gaming activities in the process of working with complex mathematical knowledge.

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### Article history:

Received: 30 August 2020

Revised: 10 January 2021

Accepted: 15 January 2021

### For citation:

Dvoryatkina, S.N., Shcherbatykh, S.V., & Lopukhin, A.M. (2021). Scientific and Methodological Support for Teachers in the Context of Gamification in Mathematics Study in the Russian System of Additional Education. *RUDN Journal of Psychology and Pedagogics*, 18(1), 140–152. <http://dx.doi.org/10.22363/2313-1683-2021-18-1-140-152>

### Bio notes

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DOI 10.22363/2313-1683-2021-18-1-140-152

Теоретическая статья

## Научно-методическое сопровождение педагогов в контексте практической реализации геймификации математического образования в системе дополнительного образования Российской Федерации

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**Аннотация.** Актуальность исследования обусловлена практической значимостью вопросов применения игровых механизмов в процессе обучения математике, неисследованностью вопросов симбиоза игровых и дидактических технологий в освоении сложного математического знания, необходимостью поиска эффективных технологий для установления их влияния на развитие обучаемого, формирование современного стиля мышления. Проведенный анализ мировых тенденций и практик внедрения элементов геймификации в систему образования установил, что освоение сложного знания и закономерностей математической деятельности, решение «проблемных зон» математики на разных уровнях обучения и сложности осуществляется комплексом математических и информационных методов без интеграции игровых элементов. Обосновано, что игровые технологии в сочетании с информатизацией математической деятельности дают мощный мотивационный заряд к изучению математики, актуализируют процессы са-

моорганизации когнитивной деятельности, способствуя развитию вероятностного стиля мышления. Целью исследования стало теоретическое обоснование и технологическое обеспечение эффективности методического сопровождения процесса профессионального повышения квалификации учителя математики в контексте геймификации математического образования с эффектом развития вероятностного стиля мышления. Разработан механизм организации и определено содержание научно-методического сопровождения педагогических работников для субъектов Российской Федерации по оказанию дополнительных образовательных услуг в контексте геймификации образования. В частности, разработаны оценочные материалы (кейс-тест) для выявления компетентностных дефицитов педагогов, обеспечивающих формирование вероятностного стиля мышления на основе процессов геймификации посредством управления информационной насыщенностью мотивационного поля обучения, предложена программа дополнительного профессионального образования для педагогов «Математика в игровой деятельности (деловые, дидактические и интеллектуальные игры)», разработаны новые формы аттестации и оценочные материалы (дидактические решения и эффективные практики на основе геймификации). Результаты использования концепта «геймификация» продемонстрировали активизацию когнитивных и мотивационных структур, в частности эффективное развитие вероятностного стиля мышления в процессе освоения сложного математического знания посредством его адаптации к школьной математике. Проведенное исследование позволяет вывести процесс обучения и развития личности обучаемого на современный качественный уровень с использованием актуальных достижений в области цифровизации образования.

**Ключевые слова:** обучение математике, повышение квалификации, геймификация, вероятностный стиль мышления

**Благодарности и финансирование.** Исследование выполнено при финансовой поддержке РФФИ в рамках научного проекта № 18-313-20002.

#### **История статьи:**

Поступила в редакцию: 30 августа 2020 г.

Принята к печати: 15 января 2021 г.

#### **Для цитирования:**

*Dvoryatkina S.N., Shcherbatykh S.V., Lopukhin A.M.* Scientific and methodological support for teachers in the context of gamification in mathematics study in the Russian system of additional education // Вестник Российского университета дружбы народов. Серия: Психология и педагогика. 2021. Т. 18. № 1. С. 140–152. <http://dx.doi.org/10.22363/2313-1683-2021-18-1-140-152>

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