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FORMING OF PROBABILISTIC APPROACH TO COGNITION AS COMPONENT OF STUDENTS PROFESSIONAL CULTURE

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Abstract

We consider the formation of probabilistic approach to the scientific cognition of students, which is the part of the systemic approach of L. von Bertalanffy. We show that researchers and teachers pay insufficient attention to the problems of formation of a probabilistic approach, despite its importance in building models of processes and phenomena of the surrounding world. We attribute this to the complex history of the recognition of probabilistic approach in Russian scientific community in the twentieth century. We dwell on the difference between a probabilistic approach to cognition and a probabilistic style of thinking. We offer the methodology for forming probabilistic approach of students when they study the probabilistic and statistical sections of the university course in mathematics. The basis of the methodology is an integrated approach to the compilation and solution of study tasks in probability theory. Students must not only answer several substantive questions on one task, but also analyze and interpret the results in accordance with the principles of probability theory and considerations of everyday logic. Students must understand the advantages and disadvantages of probabilistic models, as well as the boundaries of their applicability. We develop the ideas presented in our own manual on probability theory and mathematical statistics.

Keywords: Probability, systematic approach, statistics, teaching methods.

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1. Introduction

Since the mid-twentieth century, we notice the increase of the role of probabilistic and statistical methods in building a modern scientific picture of the world. Many laws base precisely on probabilistic models in physics, biology, computer, economic, and social sciences. Probabilistic methods in practical applications are even more significant. Famous Russian philosopher Sachkov (2013) emphasizes, “The key to understanding probability is in a new vision of the world, its structure, evolution and cognition” (p. 149).

1.1. Deterministic approach and probabilistic approach

Some time ago, the deterministic and probabilistic approaches to the description of phenomena and processes were in opposition. At present, one can speak of rigid determination and probabilistic determination, which suggests a convergence of deterministic approach and probabilistic one (Sachkov, 2001). “The real world is governed not by deterministic laws, but not by absolute coincidence” (Hodanovich, 2016, p. 588). Rigid determination means the uniqueness of a chain of cause and effect relationships, while probabilistic determination is in close connection with Markov chains. It means that at every moment there is a multiple choice of states of the object of study. We should note that we try to avoid the opposition "determinism - probabilism". They sometimes use latter term as a synonym for the probabilistic approach. Since in the scientific tradition they associate probabilism with the names of K. Popper and B. Russell, it gets a socio-political coloring that is far from the problems of this study.

1.2. Systematic approach: Russian context

From the point of view of L. von Bertalanffy, the probabilistic approach is part of a systematic approach (as cited in Hammond, 2019). In the framework of a systematic approach, they consider any object as a system, i.e. set of interacting objects (Blauberg et al., 2000). According to modern views, the system is an integral complex of elements, and their relationships are of a different nature and are probabilistic (Senatorov, 2018). Initially applied in biology, the probabilistic approach, as part of the systemic (Kudrin, 2018), become widespread in in the natural sciences (Tretter, 2019) and social ones (Hofkirchner, 2019). Some researchers played a major role in the development of the ideas of systematic approach, as well as in rethinking the meaning of the probabilistic approach in Russian science. They are P.K. Anokhin, B.V. Akhlibininsky, I.V. Blauberg, N.K. Druzhinin, B.M. Kedrov, A.N. Kolmogorov, A.S. Kravets, V.G. Levin, V.A. Lecture, A.A. Malinovsky, S.T. Melyukhin, I.B. Novik, N.F. Ovchinnikov, B.Ya. Pakhomov, L.A. Petrushenko, B.N. Pyatnitsyn, V.N. Sadovsky, Yu.V. Sachkov, V.F. Sergeants, M.I. Setrov, L.V. Smirnov, I.P. Terletsky, V.S. Tyukhtin, A.I. Uemov, E.G. Yudin, O.O. Yahot (as cited in Levin, 2017). The fact is that in domestic science there was a rather difficult period from the late 1930s to the early 1950s, when they silenced and even criticized as bourgeois the probabilistic and statistical approaches to cognizing and modeling the phenomena of the world. We can find a reflection of this situation in the work of Gnedenko (1950), who in those difficult times forced to prove the consistency and practical value of the probabilistic approach along with the deterministic one, involving the works of K. Marx, F. Engels, V.I. Lenin and I.V. Stalin. In the subsequent period, B.V. Gnedenko, A.Ya. Khinchin, A.N. Kolmogorov and others “rehabilitated” the probabilistic approach in their works

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(Gnedenko, 2017), and paved the way for non-classical thinking in domestic science (Osipov, 2010). We find the way of formation of the statistical approach in special work (Shejnin, 2016).

2. Problem Statement

Actual is the problem of the formation of a probabilistic approach as a methodology of scientific cognition of schoolchildren and students. Moreover, Raenko and Petrov (2015) argue, “It is necessary to pose a global task to the education system: to include in the didactics the conceptual principle of a probabilistic approach, which should determine the overall content of the modern style of students' thinking, and therefore the vector of development of modern science” (p. 182). Researchers propose introducing a probabilistic approach as a principle of didactics, since it is fundamental, and we could not replace it by other principles. Without sharing such radical views, we consider the problem in the following statement. Obviously, the probabilistic approach to cognition, as part of the systemic, is an important component in modeling processes and phenomena of the world. This means that its formation is one of the necessary conditions for the formation of a professional culture of a specialist. At the same time, despite the relevance of the problem, its knowledge remains low. Undoubtedly, the probabilistic approach is universal for students of all areas of training. However, the technology of humanitarian education in humanitarian universities is quite specific, and we do not have sufficient competencies to analyze this area, so we consider the subject of study as the training of students in programs of naturally scientific, technical and economic areas, as well as the training of humanities in technical universities.

3. Research Questions

The question arises about the discipline that is appropriate for the formation of a probabilistic approach for university students. From the point of view of a systematic approach, this is the task of teachers of all disciplines. They call this method of formation in pedagogy as aspectual one. However, without the universally accepted introduction into the didactics of the principle of a probabilistic approach, solving the problem in such a formulation is impossible.

3.1. Question 1: Who is in charge of probabilistic approach forming?

Therefore, the first issue of this study is the consideration and establishment of disciplinary affiliation of the technology of formation of a probabilistic approach to scientific cognition.

3.2. Question 2: What are the methods of probabilistic approach forming?

The second issue of this study is to determine the methods for forming a probabilistic approach, as well as the mechanisms for implementing this methodology. Obviously, the second and the first questions are in close relation, since the discipline and its characteristics usually determine the methods. Of course, the solution to the second question is not the only one. Therefore, we should present a reasoned solution with relative efficiency.

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4. Purpose of the Study

The purpose of the study is to identify the mechanisms of formation of a probabilistic approach to the scientific cognition (PASC) of students of technical and economic universities and to give methods for implementing these mechanisms in the course of probability theory and mathematical statistics.

5. Research Methods

The main research method is analyzing the literature on the problem. The main goal of the study of sources is to identify the possibilities for students to form PASC based on their development of various disciplines of the basic educational programs of the university. We analyze three types of sources in details.

5.1. Papers and manuals study

Firstly, these are textbooks on philosophy and its sections related to the theory of cognition. These manuals provide the development of various undergraduate, graduate and postgraduate courses of a philosophical orientation. Secondly, these are studies on the teaching of probability theory and mathematical statistics, the authors of which raise questions of the formation of PASC. Thirdly, these are textbooks on probability theory and mathematical statistics, the contents of which would correspond to the task of forming a probabilistic approach.

5.2. Pedagogical projection

Based on the data obtained, we use pedagogical projection method and present their own methodology for the formation of PASC of students.

6. Findings

We present the results of papers and manuals study bellow.

6.1. The problems of probabilistic approach forming via mastering courses in Philosophy

First, we consider the disciplines of the main educational programs, in the course of mastering which it is possible to form PASC of students. Since the study of the theory of cognition belongs to the field of philosophy, at first glance, the teachers of "Philosophy" discipline are in charge of formation of the methodology of cognition of students. However, firstly, most philosophers themselves did not study the theory of probability. Therefore, they will not be able to give students of technical and economic study fields anything more than the most general ideas about the probabilistic nature of phenomena. Secondly, students learn the discipline "Philosophy" for one semester in the first or second year. The load on it in the curricula of the natural, technical and economic fields of undergraduate studies is insignificant. This means that teachers of philosophy simply do not have time to touch in class even the basics of the probabilistic approach. As an example, we consider the manual of Rudenko et al. (2019), in which they devote no more than five pages to the entire theory of cognition. For the first acquaintance of students with a probabilistic approach, this, apparently, is enough. However, even having initial concepts about the probabilistic approach, students have no idea about the possibility of its application, not to

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mention the competencies associated with the probabilistic approach. As we already mentioned, textbooks for the training of professional philosophers concern at subtler and complex questions of the theory of cognition (Il'in, 2018).

6.2. The problems of probabilistic approach forming via mastering courses in Methodology of Science

We consider the possibilities of PASC formation in the development of the disciplines “Methodology of scientific creativity”, “Methodology of scientific research”, “Methodology of scientific activity”, etc., which are the parts of the programs of many areas of master's and postgraduate training. However, an analysis of the relevant literature does not fully confirm this. Therefore, Pesockij et al. (2017) in special manual obviously suggest that students possess the concept of approaches to scientific research from the course of philosophy, therefore they focus on research methods, limiting themselves to the opposition of metaphysical and dialectical ideas interpreted in the spirit of Marxism. Bahtina et al. (2016) consider questions of scientific cognition in a similar vein. Three other reviewed manuals – the textbook (Ruzavin, 2017), the lecture course (Lebedev, 2016), and the teaching aid (Eremin, 2019) – focus on study programs of technical universities. Therefore, authors of above manuals pay much attention to systematic approach, and, in particular, to PASC. The main characteristic of the considered manuals is their purely theoretical nature, since these are the traditions of teaching philosophical disciplines in Russian higher education.

6.3. The problems of probabilistic approach forming via mastering courses in Theory of Systems

Actually, systematic approach and systemic thinking are the basis of the content of such disciplines as "Theory of systems", "General theory of systems", "Theory of systems and system analysis", etc. These are the of bachelor's and master's programs in a number of management and cybernetic training groups. However, most authors pay little attention to the probabilistic aspects of systems theory, focusing on the tasks of the subject area of the corresponding direction of training. The exception is the book of Levin (2016) “System Studies” with an extensive section of probability and stochastics (pp. 88-127).

6.4. The problems of probabilistic approach forming via mastering courses in Probability Theory

Therefore, we showed above that teachers of such disciplines as “Philosophy”, “Methodology of scientific creativity” and even “System Theory” do not have a real opportunity to contribute to the forming PASC students. Obviously, the formation of PASC remains a natural task for teachers of mathematics who can implement it in the course of students mastering the discipline or section “Probability Theory and Mathematical Statistics”. We conducted an analysis of various Russian manuals and tasks collections on probability theory and mathematical statistics, and we presented the results of this analysis in a special paper (Krasnoshchekov & Semenova, 2014). In this research, we present only a few conclusions that are in connection with the problems of PASC formation. A significant part of the manuals focus on the development of mathematical competencies of students in the field of combinatorics

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and formal logic. Of course, these competencies are necessary for future mathematicians and IT specialists, but these competencies are redundant for students in many other areas of training. Other manuals include many tasks that require, in order obtaining a solution, to find the integrals of complex integrands. Teachers consider such tasks a continuation of the course of mathematical analysis. They refer to the principle of continuity in the teaching of mathematics. They forget or do not want to think that probability models are of a completely different nature than deterministic ones. “Hence the enormous attention paid to the actual technique of mathematical calculations, with a clear underestimation of the importance of comparing approaches and the conditions for their applicability” (Gefan, 2019, p. 23). We give only two examples of such tasks. The first example concerns task on two-dimensional random variables. Teachers offer students distributions with sophisticated expressions for probability densities that are absent in real probability models. The sole purpose of such tasks is to consolidate the skills of setting limits and calculating double integrals. Another example is finding high-order moments of continuous random variables. Ample computational work, and multiple integration in parts lead away from the probabilistic meaning of the task, especially since in most practical applications moments of the order of the fourth and higher ones do not appear. The authors also met with assignments of colleagues, in which, in order to increase the computational work, teachers suggested that students determine the values of parameters that are the known values in real distributions. The primacy of the computing component over the meaning of the assignments in no way contributes to the formation of PASC of students. The absolutizing logical and computational aspects derives in part from the somewhat neglected attitude of mathematics teachers to probability theory. In their opinion, the theory of probability, in contrast to mathematical analysis, does not have a harmonious construction, despite the efforts of A.N. Kolmogorov and others on the creation of the axiomatic base of this science. Perhaps this attitude of mathematicians to probability is an echo of the rejection of the probabilistic approach in Russian science of the mid-twentieth century, which we mentioned above (Gefan, 2015). Some, if not many, mathematicians do their best to “squeeze” the time allotted to the study of probability theory, delving into the presentation of more useful, in their opinion, sections, such as multiple integrals. Of course, remaining within the “Random Events” section, it is difficult to convey to the students the fullness, originality, and limitations of the application of the probabilistic approach. At the same time, mathematicians exactly have every opportunity to form PASC of students.

6.5. Probabilistic approach and probabilistic style of thinking

In a number of works, with the fundamental principles of which we completely agree, we find the term “formation of a probabilistic style of thinking”. First, this is the work of Dvoryatkina, Dobri et al. (2019) and her co-authors and Gefan and Kuz'min (2018). An undoubted achievement in this area is monograph of Dvoryatkina (2017). The concepts of “probabilistic approach to cognition” and “probabilistic style of thinking” are undoubtedly in close relations, including for practical consequences, but we prefer the first of them, since the second takes research into the field of psychology (Dobrin & Lopuhin, 2019). Some studies associate with the formation of probabilistic thinking of teachers (Dvoryatkina et al., 2019), without which it is impossible to form a probabilistic approach in students. Other works relate to the school environment (Patronova et al., 2011; Kovpak, 2014), however, it is

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obvious that in this case we can only talk about the formation of the probabilistic-statistical orientation of school pupils.

6.6. Probabilistic approach and probabilistic style of thinking

The purpose of the proposed methodology is the formation of PASC of students. We can achieve the goal by solving a number of tasks. Firstly, to form the teachers' readiness to introduce a new methodology. Secondly, to change the thematic focus of the collections of tasks on probability theory. Thirdly, to achieve understanding by students of the variability of the methods of obtaining results, and the variability of the results themselves. Fourthly, to teach students to understand the capabilities and limitations of PASC. Fifthly, to instill in students the skills of analyzing the obtained numerical results. To solve the tasks above we have developed a methodology for the formation of a probabilistic approach to cognition in lectures and practical classes on probability theory. The technique includes five components.

The first component of the methodology is to work with the teacher. The teachers themselves must share the fundamental position on the need for the formation of a probabilistic approach among students. Those, it is necessary to conduct a short-term refresher course for teachers, or at least several seminars. During the seminars, teachers should learn the methods of forming a probabilistic approach. Otherwise, teachers will not be able to contribute to the formation of a PASC among students.

The second component of the proposed methodology is updating the bank of tasks in probability theory, updating their topics. The purpose of the second element of the methodology is to increase student motivation. It is necessary to emphasize in tasks not their universality, based on the paradigm “mathematics is meta-science”. On the contrary, you should connect the topic of tasks with real life. Traditionally, probabilistic problems in probability theory are replete with abstract concepts as attributes of this branch of mathematics. They have become symbols that form part of mathematical culture. Around the same time, we should consider eating popcorn as a traditional part of the culture of visiting cinemas, despite its obvious harm to health. Instead of “balls” and “cards”, teachers should include in the task texts examples from private and university life, everyday life, business relations, medicine, etc. At the same time, the teachers must be aware that they are working with junior students. Therefore, one should not delve into complex professional terms and problems. Students have not yet developed a willingness to perceive the nuances of future profession, they would usually achieve this one by 4 year of study. Moreover, without the necessary professional knowledge, students will not be able to analyze the obtained numerical answers. A difficult question is the proportion of humor in tasks. Humor is certainly necessary, but you cannot turn the course of probability theory into the likeness of G. Oster's “Bad Tips”. In this case, students will spend all the creative energy on rethinking anecdotal situations in the texts of the tasks. Briefly, the task in probability theory should be a short case on the subject understandable to students, arousing their interest in the solution and giving the opportunity to interpret the results.

The third component of the methodology is the obligatory analysis of the constructed probabilistic models based on the obtained numerical results. Students under the guidance of a teacher should compare task solutions with considerations of worldly logic, without absolutizing the latter. The question *"Why is the probability of A event more likely than B event?"* is one of the main in the ongoing analysis.

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Typically, a decrease in determinism in a model entails an increase in the probability of an event. The teacher should emphasize this point with specific examples.

The fourth component of the methodology connects the characteristics of building a probabilistic model with the practical utility of the result. Accordingly, the teachers must decide for themselves and discuss with students which questions most of all allow to reveal the essence of the simulated phenomenon. We can illustrate this position by the example of a task using the Laplace formulas. *Typically, 60% of the company's projects are more expensive than the developers initially expected. What is the probability that out of 256 projects 134 will go beyond the budget?* The result is 0.22%. This value is very small and hardly makes practical sense from the point of view of company management, financial authorities, etc. It simply confirms the well-known fact that the probability of adopting a certain value of continuous random variable is zero. In this case, interval estimation gives representative information: *what is the probability that 130 to 140 projects will go beyond the budget?* This figure is already 4%. It will allow reasonably neglecting the case considered in the general analysis. However, the likelihood that from 140 to 150 projects will go beyond the budget is about 28%, which makes it possible to optimize the management of the company, and to manage human and financial resources in better way.

The fifth and main component of the methodology is an integrated approach to designing tasks. We call the integral so approach to the preparation of tasks in probability theory, in which, basing on the same initial data, students must give answers to at least three questions. This feature turns the task into a case, makes it possible to compare the results. In the example for the analysis of the company's projects, we can consider as practically significant the following issues: *1) What is the probability that more than half of the projects will not fit into the budget?2) What is the probability that less than a quarter of the projects will not fit into the budget?3) What is the probability that from 100 to 200 projects will not fit into the budget?4) What is the probability that more than 200 projects will not fit into the budget?*

To improve the methodology for the formation of PASC, one can recommend, firstly, expanding the range of issues, including those that are not usually found in collections of problems on probability theory; secondly, visualize the results using graphical computer tools. We get better results by the integral approach in probabilistic operations. For example, *Samsung provides about 23% of the global smartphone market; Huawei provides about 18%. Find the probability that three friends have: no Samsung phones (1);only one Samsung phone (2);exactly two Samsung phones (3);all Samsung phones (4);at least one Samsung phone (5);at least two Samsung phones (6);less than two Huawei phones(7);only the first Samsung phone (8);at least the first Samsung phone (9);only the first and only the second Huawei phones (10).*

Of course, you can reduce the number of questions, but we do not recommend giving them less than six in problems of this type. If students answer all questions, then they will well understand the concept of a complete group of events, which is important for monitoring the accuracy of calculations and the adequacy of the model. In addition, it is important to teach students to recognize the probabilistic alternative of "not one – at least one." Students should also pay attention to the need to give precise formulations in probabilistic modeling of phenomena. In this aspect, it is useful to compare the answers to the questions "only one - at least one - only the first - at least the first." The given example shows the differences between the integral and traditional approaches. Typically, authors of collections of

probability tasks require answers to one or two questions, which makes it impossible to analyze the results. They remain meaningless numbers for students. On the contrary, the integrated approach provides abundant food for analysis, thus contributing to the formation of PASC.

7. Conclusion

We implement our concept of the formation of a probabilistic approach to the scientific cognition of students basing on the textbook on probability theory and mathematical statistics (Krasnoshchekov & Semenova, 2013). The manual includes 1440 tasks. All of them are of 18 typical topics and have approximately the same level of difficulty, which we rate as average. Due to the large number of different tasks on one topic, we use the manual as the main tool for monitoring - conducting verification work in large academic flows of students. We invented the task of the manual taking into account the main components of the developed methodology for the formation of PASC. Firstly, we updated the subjects of tasks in comparison with traditional manuals on probability theory. Secondly, the material of the manual provides opportunities for the analysis of the results. Thirdly, we introduced an integrated approach to the preparation of assignments, leading the student to the analysis of the case. The case gives a holistic probabilistic picture of the phenomenon based on the constructed model avoiding insignificant disparate figures. The teachers of several universities in St. Petersburg and Perm approved the manual. We plan to develop the ideas of the manual with the division of tasks in three difficulty levels in order to expand the reach of the student audience. We also use the manual in classes in mathematics with foreign pre-master training students in order to form a probabilistic approach to cognition as part of their professional culture (Arseniev et al., 2019). They need to analyze the results in non-native language. On the one hand, it is certain difficult. On the other hand, it is an effective tool mastering the scientific style of Russian-language speech for future graduate-level students.

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