Peculiarities of Forming the Professional Culture of a Mathematics Teacher by Means of Digital Technologies in Higher Education Institutions of Ukraine

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Abstract: The article substantiates the professional culture of a mathematics teacher as an integrated dynamic property of a personality that projects his/her general culture in the field of profession, and is a synthesis of mathematical, scientific, methodological and pedagogical cultures of a teacher, realized in a synergistic educational space using digital technologies. The purpose of the article is to carry out a scientific and theoretical analysis of the peculiarities of the formation of the professional culture of a mathematics teacher and a future mathematics teacher, to define the concept of professional culture of a mathematics teacher, to model its main components (mathematical, scientific, methodological and pedagogical cultures), to establish their structure, to select modern digital technologies for the implementation of professional culture, to conduct a pedagogical study in higher education institutions of Ukraine and to outline possible ways of its formation in a post-industrial society. Mathematical culture includes mathematical competencies, mathematical thinking, and mathematical language. Scientific and methodological culture involves scientific research, implementation of innovative teaching and learning methods, development of the author's educational and methodological product. The pedagogical culture of a mathematics teacher is his/her ability to self-analyze, professional development; self-education, self-development, self-management, pedagogical skills; motivation, communication, professional morality, reflection, adaptability to the professional environment. The Spearman's rank correlation coefficient r_s was used to statistically test the research hypothesis. The interpretation of the size of the effect of correlation dependence was performed in accordance with the methodological recommendations of J. Cohen.

1 INTRODUCTION

The multifaceted nature of the concept of "professional culture of a teacher" leads to different approaches to its interpretation and requires in-depth research to formulate a common understanding of the content and structure of the concept of "professional culture of a mathematics teacher".

The analysis of scientific research allows us to identify a set of systemic elements that characterize professional culture as a phenomenon, namely: professional competencies, professional thinking, professional interest, professional experience, professional outlook, the degree of readiness of an individual for a particular type of activity, the ability to research, professional skill, adaptability to the professional environment, professional morality, etc. This concept includes the entire spiritual potential of an individual, intellectual, emotional and practical components of his or her consciousness.

Although foreign research emphasizes the importance of cultural factors in teacher training and performance [1, 2, 3, 4, 5, 6, 7, 8], there is limited practical experience of how culture moderates the relationship between worldview, value orientations and professional identity of teachers, especially in the Ukrainian context.

At the same time, the combination and generalisation of the key features of the culture of society, the culture of the individual and the culture of social integration in addition to and in conjunction with each other create a holistic picture of understanding culture as a scientific concept.

2 ANALYSIS OF CURRENT RESEARCH

L. Huberskyi argues that certain results of activity acquire the status of "culture" only to the extent that they contribute to the development of the essential forces of a person, the creative capabilities of the individual [9, p. 21]. Considering the activity through the prism of the diversity of its interpretations, we note that any significant result of the activity affects the formation and development of a person, and the accumulation of new achievements and values leads to an increase in the overall level of culture of society.

According to S. Honcharenko, "culture (lat. cultura – education, development) is a set of practical, material and spiritual achievements of society that reflect the achieved level of development of society and human. Culture is understood as the level of education and upbringing of a person, as well as mastery of a certain field of activity" [10, p. 182].

In our research, we will take as a basis the following definition of culture as a complex (totality) of material and spiritual achievements of society, symbolic products of personality development (dispositions, knowledge, abilities, creative forces, value orientations, etc.) and technologies for the implementation of any purposeful activity in a specific human environment [11].

I. Glazkova et al. [12, pp. 144-161] analyze the phenomenon of professional pedagogical culture as a socio-pedagogical phenomenon that integrates historical and cultural experience into coordinated pedagogical activity.

The article [13, pp. 42-53] aims to explore the relationship between educational practices, professional culture and sustainable development goals, in particular in the context of the Ukrainian national educational system and professional community.

The article [14, pp. 17-25] highlights the theoretical foundations of the professional culture of future specialists in accordance with the global challenges of the information society, concludes that the main components of the content of professional culture are motivation to master special professional knowledge, skills, professionally significant values, which in the process of forming professional culture should become personally significant.

The works of [15, 16, 17, 18, 19] are of great importance for our research.

The purpose of the article is to define the concept of professional culture of a mathematics teacher, model its main components (mathematical, scientific, methodological and pedagogical cultures), establish their structure, select modern digital technologies for the implementation of professional culture, conduct a pedagogical study on the peculiarities of the formation of professional culture of a mathematics teacher and a future mathematics teacher in higher education institutions of Ukraine and outline possible ways of its formation in a post-industrial society.

The structure of the study is based on the principle from the general to the specific, which allows us to consistently consider both the theoretical foundations of the problem and its practical aspects.

3 DIGITAL TOOLS IN THE FORMATION OF PROFESSIONAL CULTURE OF A MATHEMATICS TEACHER

The formation of professional culture of a mathematics teacher and a future mathematics teacher is possible with the use of system-activity, synergistic, competence, prognostic, personal development, educational, research and information approaches that allow improving the quality of education and personal awareness.

The basis of the methodological approach to the study of the personality of a high-level mathematics teacher is to substantiate and verify the peculiarities of the formation of his/her professional culture while working in a higher education institution.

Using the cultural approach [9, 10], it is possible to assess the professional culture of a mathematics teacher through a system of criteria that reflects his or her ability to cultural self-identification and integration into the professional community.

For us, the study of H. Mykhalin is especially valuable, as he revealed the content of the concept of "professional culture of a mathematics teacher" as a set of practical, material and spiritual achievements

that determine the quality of the teacher's professional activity [20, p. 30]. The scientist considers mathematical, methodological, pedagogical, psychological, informational, linguistic and moral cultures to be the main components of the professional culture of a mathematics teacher and notes that each of these components of the professional culture of a specialist, in particular a mathematics teacher, with the exception of moral culture, consists of general and special parts, and its content significantly depends on the specifics of the specialist's activity.

Based on the analysis of scientific literature, we understand the professional culture of a mathematics teacher as an integrated dynamic property of a personality that projects his or her general culture in the field of the profession, is a synthesis of mathematical, scientific, methodological and pedagogical cultures, and is realized in a synergistic educational space using digital technologies. Since digital technologies play a fundamental role, we include them in all components of the professional culture of a mathematics teacher (Figure 1).

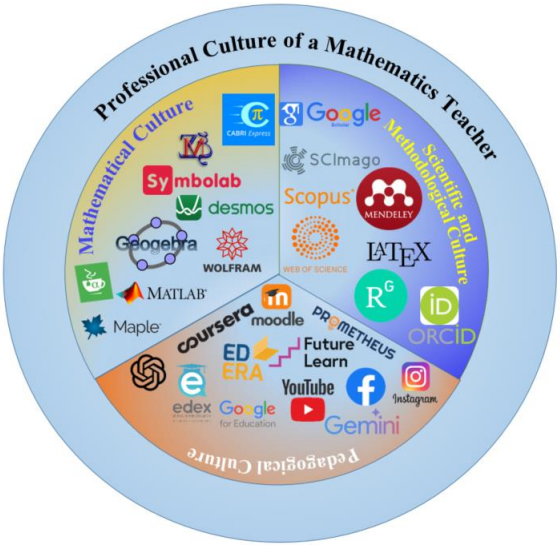

Figure 1: Professional culture of a mathematics teacher (author's development).

Let's consider the first dynamic property of the professional culture of a mathematics teacher - mathematical culture, which reflects the formation of a system of mathematical knowledge and skills, mathematical thinking and mathematical language, developed ability to self-education, which form the professional worldview of a mathematics teacher.

The problem of mathematical culture is addressed in the articles of both mathematicians who considered it from the mathematical aspect and scientists-pedagogues who studied it from the methodological aspect. In particular, Ye. Lodatko interprets the mathematical culture of society as "a complex social formation that is formed under the influence of mathematical traditions, an established system of mathematical education and mathematical achievements" [21, p. 78]. H. Zinchenko emphasizes that "the mathematical culture of the future mathematics teacher is determined not only by the high level of mastery of mathematical knowledge, the ability to use it in practice, mathematical language and speech, but also by the teacher's own system of values, his/her general worldview erudition and, most importantly, the ability to form this culture in students" [22, p. 92]. The analysis of the structural components of mathematical culture is carried out in [23, pp. 52-56].

The mathematical language allows mathematics educators to describe the world with unique precision and conciseness. Unlike natural languages, which are prone to ambiguity and contextual nuances, mathematics offers a rigorous formalism where each concept has a clear definition and statements can be proven or disproven through logical reasoning. This precision makes mathematics indispensable in science, technology, and many other areas of human activity.

Back in 1927, H. Williams wrote that mathematics is both a source of truth and a special language. The mathematical language is more defined and abstract than our usual means of thinking and communicating [24].

The main skills related to the mathematical language of a mathematics teacher: to know mathematical terminology, in particular in Ukrainian and English; to present educational material competently; to be able to highlight the main thing in mathematical sentences; to justify mathematically correct problem solving; to use computer mathematics systems.

Mathematical competence includes a culture of logical and algorithmic thinking, knowledge and ability to apply mathematical (numerical and geometric) methods to solve applied problems in various fields of activity, the ability to understand and use mathematical models and the ability to build such models to solve problems [25].

The ability of a mathematics teacher to work with digital mathematical tools such as Maple, MATLAB, GeoGebra, Maxima, MathCha, Symbolab, Wolfram Alpha, MathWorld, Desmos, etc. ensures the formation of his/her mathematical culture.

According to O. Maksymovych, “mathematical thinking is a complex process in which students master high-level thinking skills, namely: they learn to analyse, synthesise, generalise, classify, compare, etc. Mathematical thinking is one of the values of a person, and it is formed due to the mathematical activity of a person in the process of learning mathematics” [26, pp. 125-129].

Let's consider the scientific and methodological culture, which is a multifaceted component of the professional culture of a mathematics teacher and combines his/her scientific activity, implementation of modern teaching and learning methods, and development of his/her own educational and methodological product.

The formation of the scientific activity of mathematics teachers is ensured by the use of academic search engines (Google Scholar, Scopus, Web of Science, ORCID, Scimago Journal & Country Rank), professional document preparation systems (LaTeX), bibliographic managers (Mendeley, Zotero, EndNote), scientific communities (ResearchGate, Academia. edu) for writing and publishing articles, monographs, preparing and defending dissertations, projects and grants, obtaining titles of protection (patents, copyright certificates) for intellectual property rights.

Teaching and learning methods include the ability of a mathematics teacher to combine traditional and innovative approaches, methods, techniques, forms and means through modern digital technologies and digital competencies. As co-authors of the article [27, pp. 93-106], we propose a foresight wheel of digital technologies for use in the educational process, which represents a classification of teaching aids depending on the type of classes.

The educational and methodological product of a mathematics teacher consists of writing, editing, reviewing textbooks, teaching guidelines, workbooks, developing lectures, practical and laboratory classes, work programs and silabuses, tests and control works, which are placed in virtual mathematical educational environments. The design and development of such educational environments is carried out by means of content management systems (Moodle, WordPress, Drupal), testing systems (Kahoot!, Quizizz), online conferencing platforms (Zoom, Google Meet, Microsoft Teams), etc.

The article [28, pp. 51-57] investigates the potential of modeling a virtual mathematical educational environment on the example of a website, and identifies which tools and technologies can be used to create it.

The article [29] reveals the structure of digital competences through the following areas of activity: professional engagement, digital resources, teaching and learning, assessment, experiential learning, and promotion of students' digital competence.

In our professional activities, we pay special attention to the modern digital textbook in mathematical disciplines in the preparation of a bachelor of mathematics. After all, a a high-quality digital textbook ensures the formation of not only the mathematical culture of the future specialist, but also the formation of such basic competencies as the ability and willingness to self-learn, apply knowledge, skills and abilities to work with computer mathematics systems, self-education and future professional activities. The use of a digital textbook integrated into the learning technology designed and implemented by the teacher allows him or her to choose their own creative strategy and methodology for teaching students.

The pedagogical culture of a mathematics teacher, as an integral part of his/her professional culture, in a post-industrial society combines the ability to self-analyze his/her own professional activity and the desire to improve skills; the level of self-education, self-development, self-management; the presence of motivation, communication, professional morality and reflection of the teacher as components of the individual trajectory of his/her professional development.

The analysis of the essence of the concepts of “culture”, “independent work”, “professional culture” in the context of philosophical, cultural and pedagogical knowledge, various methodological approaches allowed to define the culture of independent work of a mathematics teacher as an integrative property of his personality aimed at accumulating general and professional competencies, motivational characteristics and volitional qualities during independent work in the conditions of professional activity.

Online courses on the Coursera, edX, Udemy, Prometheus, Future Learn platforms; task and project planning tools Google Calendar, Trello, Asana; social networks for professional networking LinkedIn, Facebook, Instagram; online forums, discussions, personal websites, blogs, etc. will be useful for teachers' independent work.

Each component of a mathematics teacher's professional culture is a prerequisite for success in teaching. However, not every mathematician who has succeeded in his or her research is a good

teacher even in the field of his or her narrow specialty [20], just as a specialist in methodological or pedagogical research can become a highly qualified mathematics teacher.

The formation of the mathematical culture of a mathematics teacher begins in the master's program, where the corresponding additional specialty is provided. And the discipline "Methods of teaching mathematics in higher education" sets one of the tasks to familiarize master's students with the peculiarities of the methodology of teaching mathematics courses in higher education institutions of different levels and professional orientation; to reveal the goals, content, methods and means of studying individual mathematical disciplines.

Let us consider the example of the topic "Methods of teaching functions in mathematical analysis. The Limit of a Function", how these concepts are formed, starting from the function of one variable, two and many variables to the concept of mapping, operator and functional in a metric space. We use the methods of analogy, comparison, highlighting the main and differences in the definition of this concept in different metric spaces.

If we use the method of analogy and generalization, we see that in all cases of j-value functions of one variable, many variables, and mapping to metric space, keywords are preserved: "one for each".

If you use the comparison method, the objects of study change. In some cases, these are numbers, in others, points of the Euclidean space, and in metric spaces, points can be functions, numerical sequences, and other objects. We point out that objects of different nature can appear in the definition domain and the value domain:

Function of single variable (Figure 2)**.**

$$\text{for each } x \in X \subset \mathbb{R} \overset{f}{-} \text{ single } y \in Y \subset \mathbb{R}.$$

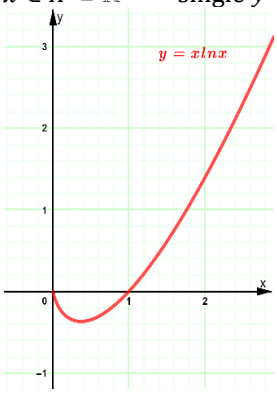

Figure 2: Graph of a single variable function (built in MathCha).

Function of many variables (Figure 3)**.**

$$\text{every point of } x = (x_1, x_2, \dots, x_n) \in E \subset \mathbb{R}^n \overset{function}{-} \text{single number } y \in \mathbb{R}.$$

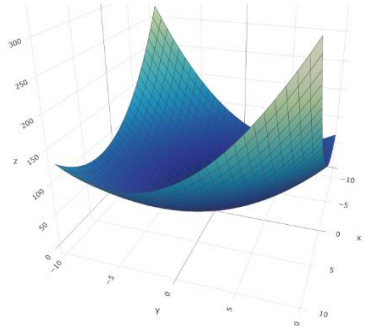

Figure 3: Graph of the function of two variables (built in MathCha).

Display in metric space. A mapping f, which corresponds to each point of the metric space X to one point of the metric space Y, is called a mapping from the metric space X to the metric space Y.

Similarly, to introduce the concept of the limit of a function, we can also use the method of analogy, generalization, and comparison, to show that the Heine definition, regardless of the nature of objects, is formally written in the same way:

$$\left(A = \lim_{x \to x_0} f(x)\right) \overset{df}{\Leftrightarrow} \left(\forall (x_n) \subset O^*(x_0) \cap X : \lim_{n \to \infty} x_n = x_0 \Rightarrow \lim_{n \to \infty} f(x_n) = A\right).$$

The definition of the boundary of a function at a Cauchy point depends significantly on how the distance is denoted in a particular metric space.

The limit of a function of a single variable**:**

$$\left(A = \lim_{x \to x_0} f(x)\right) \overset{df}{\Leftrightarrow} (\forall \varepsilon > 0 \exists \delta > 0, \forall x \in X : 0 < |x - x_0| < \delta \Rightarrow |f(x) - A| < \varepsilon).$$

In the definition of the boundary of a function of many variables, the points $\mathrm{x_0} = (\mathrm{x_{01}}, \mathrm{x_{02}}, \dots, \mathrm{x_{0n}})$ of the Euclidean space $\mathbb{R}^{\mathrm{n}}$ and numbers appear, so we pay attention to the distance notation:

$$\left(A = \lim_{\substack{x \to x_0 \\ x \in E}} f(x)\right) \overset{df}{\Leftrightarrow} (\forall \varepsilon > 0 \exists \delta > 0, \forall x \in E : 0 < d(x, x_0) < \delta \Rightarrow |f(x) - A| < \varepsilon).$$

Here it is important to realize that the point M_0 can be approached in different ways (in fact, there are many such ways), and this will significantly

affect the further construction of the theory of functions of many variables, in particular, its differentiability.

To define a mapping boundary in the metric spaces X and Y, we take into account that objects can have different natures, so we denote their distances by $d_1(x, x_0)$ and $d_2(f(x), y_0)$, respectively. Thus, we conclude that in metric spaces, the construction of the theory of mapping boundaries depends on the nature of the objects and there may be interesting surprises.

A mathematics teacher must have the appropriate competencies to explain the fundamental concepts of "function" and "limit of function" to higher education students in a methodologically competent manner.

4 DISCUSSION

The authors of the article conducted a pedagogical study in higher education institutions of Ukraine on the peculiarities of forming the professional culture of a mathematics teacher and a future mathematics teacher. Respondents ranked the components of professional culture at the level of their structures using Google Form. The results of the primary data and intermediate calculations based on the survey of mathematics teachers and future mathematics teachers are presented in Table 1.

Table 1. Table of primary data and intermediate calculations based on the results of the survey of mathematics teachers (X_i) and future mathematics teachers (Y_i).

n	Component structure	X_i	Y_i	d_i	d_i^2
1	Mathematical competencies	2	2	0	0
2	Mathematical thinking	1	1	0	0
3	Mathematical language	3	3	0	0
4	Scientific research	9	7	2	4
5	Teaching and learning methods	4	5	-1	1
6	Educational and methodological product	8	9	-1	1
7	Self-analyze, professional development	7	4	3	9
8	Self-education, self-development, self-management, pedagogical skills	6	6	0	0
9	Motivation, communication, professional morality, reflection, adaptability to the professional environment	5	8	-3	9
			Sums	0	24

In order to establish a statistical relationship between the indicators of the significance of the components of professional culture at the level of their structures in mathematics teachers (48 people) and future mathematics teachers (53 people), Spearman's rank correlation coefficient r_s was used, which is determined by the formula: $r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$, where d_i is the rank difference; n is the number of features (Table 1) [30, pp. 59-63]. The study was conducted in higher education institutions of Ukraine with maximum respect for the privacy and confidentiality of the subjects, in compliance with the ethical norms and standards of the American Psychological Association (APA), the recommendations of the Ethical Code of the Scientist of Ukraine.

The primary data on the two parameters are presented in an order scale. The ranks are not repeated, so the empirical value of Spearman's r_s correlation coefficient will be determined by the general formula. We set the probability level of the first kind of error and formulate the null and alternative hypotheses for $\alpha = 0.01$:

- H_0: the indicators of the importance of professional culture components at the level of their structures for mathematics teachers and future mathematics teachers are not interrelated ($r_s = 0$);
- H_1: the indicators of the importance of professional culture components at the level of their structures for mathematics teachers and future mathematics teachers are interrelated ($r_s \neq 0$).

Calculate d_i – rank differences by the formula: $d_i = R_{X_i} - R_{Y_i}$; d_i^2 – squares of rank differences; sums of d_i^2 for the sample of subjects.

We calculate the empirical value of the Spearman's rank correlation coefficient using the formula r_s:

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} = 1 - \frac{6 \cdot 24}{9 \cdot (9^2-1)} = 0.8.$$

This value indicates a direct correlation of the average force between the variables. Let's check its statistical significance.

According to the table of critical values of Spearman's correlation coefficient r_s [30, p. 130] for $df = n = 9$ and a given $\alpha = 0.01$, we find $r_{\text{crit}} = 0.798$. Since $|r_{\text{emp}}| > r_{\text{crit}}$ $(0.8 > 0.798)$, the hypothesis H_0 is rejected. The size of the standardized effect according to J. Cohen's classification is large ($r_s = 0.8$).

Thus, there is a statistically significant relationship between the indicators of the significance of the components of professional culture at the level of their structures among mathematics teachers. According to the statistics of Spearman's r_s criterion ($r_s = 0.8$; $p > 0.01$; $n = 9$), there are no grounds for accepting the null hypothesis.

There are common points of view on the ranking of components of professional culture of teachers and future teachers of mathematics. The significance of the indicators coincides with the ranks 1 (Mathematical thinking), 2 (Mathematical competencies), 3 (Mathematical language), 6 (Self-education, self-development, self-management, pedagogical skills). The significance of the indicators “Teaching and learning methods” and “Educational and methodological product” has a minimal difference (difference), represented by ranks 4-5 and 8-9, respectively.

The results of the study have shown that the indicators of the significance of the components of professional culture at the level of their structures in mathematics teachers and future mathematics teachers are interrelated. The statistically significant reliability of the study was confirmed by the Spearman's rank correlation coefficient r_s, performed in accordance with the methodological recommendations of J. Cohen.

5 CONCLUSIONS

The authors of the article have carried out a definitional analysis of the key concepts of the study. It is shown that the professional culture of a mathematics teacher combines three main components: mathematical, scientific, methodological and pedagogical cultures, which, in turn, are complex integrative formations and are closely interrelated. The formation of professional culture is possible only with the use of digital tools in all its components. We propose to use the wheel of digital technologies modeled in the article, which identifies the main directions of implementation of modern tools in the professional activity of the teacher.

By the professional culture of a mathematics teacher, we mean an integrated dynamic property of a personality that projects his or her general culture in the field of the profession, is a synthesis of mathematical, scientific, methodological and pedagogical cultures, and is realized in a synergistic educational space using digital technologies. Digital technologies have become an integral part of the modern world, and education is no exception. Their integration into all components of the professional culture of a mathematics teacher is fully justified and necessary. The conducted pedagogical research in higher education institutions of Ukraine has shown that the indicators of the significance of the components of professional culture at the level of their structures in mathematics teachers and future mathematics teachers are interrelated. To statistically test the hypothesis, the study used Spearman's rank correlation coefficient r_s. Interpretation of the size of the effect of correlation dependence was performed in accordance with the methodological recommendations of J. Cohen.

Prospects for further research are seen in a detailed analysis of the structural components of the professional culture of a mathematics teacher, the definition of local and global goals, objectives and methods of their implementation.

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