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Holistic Approach to Teaching Mathematics in Secondary School as a Means of Improving Students' Comprehension of Study Material

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Abstract**—**Creating favourable conditions for students' comprehension of mathematical content is one of the primary problems in teaching mathematics in secondary school. The fact of comprehension includes the ability to build a working situational model and thus becomes an important means of solving mathematical problems. This paper describes a holistic approach to teaching mathematics designed to address the primary challenges of such teaching; specifically, the challenge of students' comprehension. Essentially, this approach consists of (1) establishing links between the attributes of the notion: the sense, the meaning, and the term; (2) taking into account the components of student's subjective experience—value-based emotions, contextual, procedural and communicative—during the educational process; (3) linking together different ways to present mathematical information; (4) identifying and leveraging the relationships between real, perceptual and conceptual (scientific) mathematical spaces by applying real-life situational modelling. The article describes approaches to the practical use of these foundational concepts. Identifying how proposed methods and techniques influence understanding of material used in teaching mathematics was the primary goal. The study included an experiment in which 256 secondary school students took part: 142 in the study group and 114 in the control group. All students in these groups had similar levels of achievement in math and studied math under the same curriculum. In the course of the experiment, comprehension of two topics — "Derivative" and "Trigonometric functions"—was evaluated. Control group participants were taught using traditional methods. Students in the study group were taught using the holistic method: under teacher's guidance, they carried out assignments designed to establish linkages between notion's characteristics, to convert information from one mode of presentation to another, as well as assignments that required the ability to operate with all modes of presentation. Identification, accounting for and transformation of subjective experience were associated with methods of stimulating the emotional value component of the studied mathematical content (discussions of lesson titles, assignments aimed to create study dominants, performing theme-related physical exercise ...) The use of techniques that forms inter-subject notions based on linkages between, perceptual real and mathematical conceptual spaces proved to be of special interest to the students. Results of the experiment were analysed by presenting students in each of the groups with a final test in each of the studied topics. The test included assignments that required building real situational models. Statistical analysis was used to aggregate test results. Pierson criterion x^2 was used to reveal statistics significance of results (pass-fail the modelling test). Significant difference of results was revealed ($p < 0.001$), which allowed to conclude that students in the study group showed better comprehension of mathematical information than those in the control group. The total number of completed assignments of each student was analysed as well, with average results calculated for each group. Statistical significance of result differences against the quantitative criterion (number of completed assignments) was determined using Student's t-test, which showed that students in the study group completed significantly more assignments than those in the control group ($p = 0.0001$). Authors thus come to the conclusion that suggested increase in the level of comprehension of study material took place as a result of applying implemented methods and techniques.

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Keywords**—**Comprehension of mathematical content, holistic approach to teaching mathematics in secondary school, subjective experience, technology of the formation of inter-subject notions.

I. Introduction

NOWADAYS, one of the significant challenges in the school education system is the search for ways and approaches of forming and maintaining the interest of the secondary school students in mathematics, and the motivation for studying mathematics as a school subject. However, according to psychologists, resolution of a problem with motivation does not ensure a constant interest in the subject. No matter how significant a place the subject of mathematics occupies in the student's mind, this interest in mathematics is impossible to maintain without understanding its substance. Thus, the lack of comprehension of the content leads to the decrease or disappearance of cognitive interest.

A solution to the problem of comprehension would require appealing to the child's personality and their subjective experience, especially since personal development is the primary assumed purpose of secondary education. With this in mind, developing a conflict between the students' subjective experience (SE) and their mathematical experiences of a socio-historical nature. During studies, these contradictions between the social experience and their subjective forms are revealed through analysing problem-based situations. Thus, we formulate problem-based developmental learning as the highest level of the holistic approach to teaching. "The teaching process in its genesis has passed through a number of development stages from the dogmatic type to the explanatory and illustrative one, and then to the problem-based developmental type. At the same time, the level of integrity has been becoming higher, and currently, the process of problem-based developmental learning corresponds to the high level thereof. The integrity of the process of problem-based developmental learning is characterised by its internal unity, cohesion, qualitative definiteness, and significant results in the development, education and socialisation of the students" [1].

We have identified three aspects in the implementation of a holistic approach in the process of teaching mathematics: philosophical, psychological and pedagogical, and genetic aspects.

1. Philosophical aspect: A holistic approach to teaching is implemented in the context of organisation of the interconnection between three types of spaces: real, conceptual, and perceptual [2]. Each conceptual space has its own conceptual framework. In the course of education, a secondary school student gets acquainted with the real space through the study of various conceptual spaces, and the relationships between them (including interdisciplinary) are established. A child already has ideas about the real space at the sensory level, and these ideas are personalised and are often far from an objective evaluation. Teaching mathematics should help the students to bring their own perceptual space to the real one to the greatest possible extent through working in conceptual spaces through the development of mathematical models.
2. Psychological and pedagogical aspects: A student internalises any information through their own SE, therefore, it is required to identify and take this SE into account in the teaching process, i.e., it is necessary to organise the introduction of new educational material in such a way so that the acquired knowledge "fits" into the existing framework of knowledge and ideas of a student. Moreover, all aspects of the SE should be taken into account in the teaching process. Besides, the comprehension of information depends on a student's dominant thinking style, hence it is necessary to take into account the specifics of different thinking styles (they are mainly reduced to the creative and logical ones). Therefore, it is necessary to provide opportunities for consideration of both creative and analytical strategies for solving the tasks upon teaching mathematics.
3. Genetic aspect: The teaching process should be based on a genetic approach to conceptualisation with the use of specific features of conceptualisation both in the history of science and in the genesis of a student's personality. A teacher should organise the educational activities of the students in such a manner as to lead the students up to the discovery of a certain concept, for example, through the problem-based situation organisation. The educational material should be presented with due regard for the genesis of its development, which is implemented within the framework of the genetic aspect of a holistic approach to teaching. A holistic approach to the concept is implemented through establishing links between the characteristics of a concept: a term (a name), values and meanings of this concept presented in different ways (verbal, sign-oriented and symbolic, figurative and graphic, tactile and kinaesthetic ways). In the context of mathematics, terms denote those mathematical entities that are objects of the study of mathematics. The meanings of concepts are ideas since the mathematical entities are inherently abstract and do not exist in the real world. A value of a concept can be conveyed by a definition, an axiomatic system, an attribute, a description of properties of entities essential to the concept, etc.

The specified aspects characterise the conditions that ensure the comprehension of mathematical information. These conditions correspond to the interpretation of comprehension proposed by psychologists Kandybovich and Dyachenko [3]. They consider comprehension as a process of 1) inclusion of new information in the SE of a student, 2) establishment of links between different characteristics of a concept presented in different ways. According to Frege, characteristics of a concept include a term (name or title), a value (concept content), and a meaning (denotation) [4]. These components of comprehension are manifested through the above-mentioned aspects of a holistic approach to teaching mathematics. We have developed certain techniques and methods for the implementation of each aspect of the holistic approach. The main research question has consisted in the identification of the influence of the proposed techniques and methods on the comprehension of educational material in mathematics.

II. Literature Review

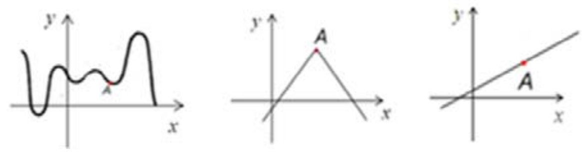
The value of the concept of "comprehension" attracts the attention of many scientists both to the interpretation of the concept itself and to the resolution of a problem with the creation of conditions ensuring the comprehension of information, in particular, educational one. Thus, Zinchenko considers comprehension as an ability to perceive the value and the meaning of a cognizable object, phenomenon, text, and this comprehension is associated with the identification of essential elements and their interrelations [5]. The comprehension of the value of a cognizable object is often based on the reflection of relations, connections of this object in the consciousness with what is already in the consciousness of a person. This represents the development of a holistic view of the object, which includes substantive, logical, and emotional components. Brudny emphasizes the possibility to assemble a functioning whole called a semantic field from the existing elements of knowledge, ideas, attitudes, and sensations, in the process of comprehension [6].

A study by Wiggins and McTighe [7] emphasizes that knowledge is necessary but insufficient for comprehension; comprehension is not a direct function of knowledge. Comprehension is the result of a deliberate attempt to think through and connect individual experiences, phenomena, as well as knowledge and skills. The pedagogical research in this regard resolves the problem of comprehension in teaching mathematics. Thus, Sapegina suggests using educational mathematical situations, the consideration of which occurs in a dialogue, as the primary means of organisation of the teaching process. Questions framed in a certain way, hypotheses that make the students think, see a contradiction, or establish a new relationship or a lack of knowledge, misunderstanding [8], perform the main function in the creation of educational mathematical situations.

A lot of researchers distinguish three levels in the process of comprehension itself: a gradual change in the structure of a situation being recreated in the consciousness (semantic field arrangement), the movement of the conceptual centre of the situation from one element to another (semantic field realignment), and the construction of a whole (a transformed concept due to decentration) [6], [9]-[11]. When a student passes through these levels, a change in the value of the revealed connections, provision of knowledge with the value, and a transition to a new quality called "living knowledge" happen [5].

According to the researchers, the emergence of conceptual knowledge should be arranged by properly prepared practical classes supported by manipulative materials that can combine extensive mathematical ideas with familiar physical tools related to the real world [12]. This conclusion confirms the expediency of identification and usage of the interconnection between the real, perceptual and conceptual (scientific) mathematical spaces by simulation of real situations in the educational process.

When studying mathematics, the knowledge of concept definitions and wordings of assertions and formulas is not a sufficient condition for a successful solution of a problem. The analysis of various studies [9], [13]-[15] allows us to conclude that to choose methods of solution and implement them, a secondary school student must be able to characterise certain mathematical concepts based on their interconnection with the others and to create different interpretations of task situations. The researchers [9], [15] associate such usage of the existing knowledge with the functioning of comprehension and consider knowledge as a psychological basis of comprehension. The description of a task situation contains various concepts in an explicit and implicit form. It is necessary to establish links between the concepts in order to understand it. In the process of education, when arranging a semantic field, i.e., when moving in chain order from one concept to another, the cognize does not always have the opportunity to see the links between the non-neighbouring elements of this field. One of the reasons for the difficulties is that concepts can be represented by different characteristics: a value, a meaning, and a term (the logical triangle of a concept) [4]. However, systematic work with the school students aimed at the establishment of the links between the characteristics of a concept is not organised in the process of teaching mathematics [16]. According to the researchers, this work requires the actualisation of such psychological mechanisms as realignment and decentration when working with the concepts [6]. As shown in [17], links between concepts not revealed in the teaching process, and the lack of work on realignment and decentration, arrangement of a semantic field of mathematical concepts lead to difficulties in mastering mathematical concepts, in solving tasks, and, therefore, in the comprehension of mathematical information. Another possible reason for the inability to establish links between the concepts, and, therefore, the inability to create a complete image of an object (task situation) is the lack of work on the representation of objects in different forms, as well as the transformation from one to another. Thus, it was shown in our earlier study [19] that not only students but also teachers have difficulties in the establishment of the links between different forms of representation. For example, less than 20% of teachers and less than 5% of school students have coped with the task "Draw a secant and a tangent line to the function graph at point A (Figs. 1 (a)-(c)".



(a) (b) (c)

Fig. 1 Function graphs

Fig. 1 (c) has resulted in particular difficulties and a variety of answers. Most of the task solvers answered that the tangent line does not exist. However, when they were asked to find the derivative of a linear function, almost everyone has found it correctly. This example shows that not only a lot of school students but also teachers do not see the connection between the characteristics of the concepts, as well as between their different forms of representation. In this example, the task solvers have not been able to establish a connection between the term "derivative of a function at a point" and the values thereof represented graphically (the tangent of the tangent slope angle drawn to the function graph at the point) and analytically (the formula of the derivative of the linear function).

A school student is a subject of the teaching process. Having come to school, they already have their own experience of cognition of the world around them. According to psychologists, scientific information is given through the content of the educational material, and a child "internalises" it through their own SE upon mastering thereof and turns it into their individual knowledge [19]. This experience is acquired not only through communication in the family, with peers and other people, or through information sources, but also in the process of directive teaching. "Knowledge is no longer considered a reflection of what has been given to a person from the outside; it is an individual construct, to which a person gives meaning by correlation of the elements of knowledge and experience with a certain organizing scheme" [20]. A teacher introduces the students to the scientific, historical, and social experience in the field of mathematics. However, the transfer of the scientific information by a school student in accordance with their SE may not result in scientific knowledge. Thus, Yakimanskaya [21] considers a situation when a student of the ninth grade was giving correct answers upon solving the quadratic equations if the task had the following wording: "Solve the quadratic equation". If it was proposed to find a root of the quadratic equation, her answers were incorrect. It emerged that the concept of "a root of a quadratic equation" was associated with the concept of "a square root of a number", which had been studied earlier, in her SE. The authors have also repeatedly encountered similar situations in their practice. Therefore, teaching consists in the "improvement" of the SE, and the teacher's task is to prepare a student for a re-evaluation of their SE, rather than to convey their own SE under the guise of the sociohistorical one [22]. According to the psychologist Yakimanskaya, teaching should contribute to the identification and structuring of the student's SE and its coordination with the socially significant experience. The holistic approach is considered as an encounter of these two types of experience in her study [19]. Varghese understands the holistic approach as a balance between the student-oriented and the teacher-oriented approach to teaching mathematics [23].

The researchers [24] primarily distinguish the following aspects in the structure of the SE:

- substantive aspect (objects, representations, concepts),
- procedural aspect (operations, techniques, rules for performance of mental and practical actions),
- emotional and value-based aspect (personal meanings, attitudes, moral stereotypes),
- communicative aspect (communication skills, behavioural patterns in communication).

The consideration of the SE of a child concerns not only the substantive aspect but also the procedural one associated with their own ways of comprehension and processing of the information. When the students reject their own strategies, it gradually leads them to the idea that mathematics is disconnected from real life. The students unconsciously conclude that other laws, rules, and methods apply in math lessons. They are different from those applied in real life. As a result, the students do not demonstrate critical thinking in the process of mathematical activity. It results in the appearance of fractional numbers in answers to the tasks aimed at determination of the number of people, the appearance of images of sharp angles in the tasks aimed at constructing angles of greater than 90°, etc.

For the content introduced by a teacher to have a personal meaning for a student, it must be consistent with the student's values, attitudes, ways of processing information, and the student's attitude to the knowledge content. Moreover, the peculiarities of the children's comprehension of educational material in the classroom should be taken into account upon organisation of teaching. Thus, Sousa, an international consultant in educational neuroscience, has constructed a graph showing the dependence of memorisation on the time elapsed since the beginning of a lesson (Fig. 2) [25].

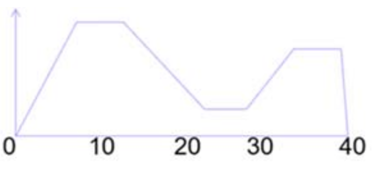


Fig. 2 Changing during the lesson [25]

Consequently, the literature review has allowed us to identify the fundamental principles of the implementation of a holistic approach that contribute to the school student's comprehension of mathematical information. They consist in 1) establishment of the links between the characteristics of a concept: a value, a meaning, and a term, 2) establishment of the links between different ways of representation of mathematical information (verbal, sign-oriented and symbolic, figurative and graphic, tactile and kinaesthetic ways), 3) consideration of the aspects of the SE of a school student in the teaching process: emotional and value-based, substantive, procedural and communicative aspects, and 4) establishment of a correlation between the real, perceptual and scientific mathematical spaces in the teaching process.

The comprehension of an object is characterised by the ability to build your own effective object model with the use of various forms of information representation and links between them. Therefore, the tasks aimed at the assessment of the competency in this skill can be used as an indicator of the presence of comprehension.

III. Methodology

We have developed techniques and methods for each of the specified principles for the implementation of the holistic approach. These techniques and methods have been used in the process of teaching mathematics in order to create conditions that ensure the comprehension of mathematical information.

1. Establishment of the Links between the Characteristics of a Concept: A Value, a Meaning, and a Term

Each concept combines a set of objects (denotation) and essential properties inherent in all elements of this set (concept content). The connection of all three characteristics of a concept (term, value or content, meaning or denotation) can be represented with the use of the logical triangle of Frege [4]. One and the same concept can have more than one value and (or) more than one meaning and in this case, the Frege triangle is transformed into a series of triangles, additional vertices appear for each of the characteristics, including from the SE of the students, while all the characteristics must be interconnected. Therefore, it is advisable to provide the students with the tasks for the use of the Frege triangle, i.e., to describe the values of a given term, to define the denotation, or to define the term of the described value (values) of a concept. For example, as regards the concept of "the sine of an angle α", the students have been asked to describe its value (values), i.e., to define it (them) through different properties, and to determine what the values of the sine of this angle are. The students have offered the following as the answers: a trigonometric value equal to the semi-chord of the double arc, on which the angle rests; a length of the perpendicular line dropped from the end of the arc to the radius of the unit circle; a ratio of the cathetus opposite the triangle angle to the hypotenuse of this triangle. The meaning of this concept is the number [26].

Another effective method for the establishment of the links between the concepts is the representation of relations between the denotations using Euler circles. Its use is based on the mechanism of decentration necessary to ensure comprehension.

2. Establishment of the Links between Different Ways of Representation of Mathematical Information (Verbal, Sign-Oriented and Symbolic, Figurative and Graphic, Tactile and Kinaesthetic)

In order to develop the corresponding skill, it is advisable to offer students problems, in which different values and meanings are invoked, which are represented in different ways (forms), all the way to the tactile and kinaesthetic one.

- Problem 1. Which cards describe the same mathematical concept (Fig. 3)? Note that the characterised concepts are circled on the cards with graphs.

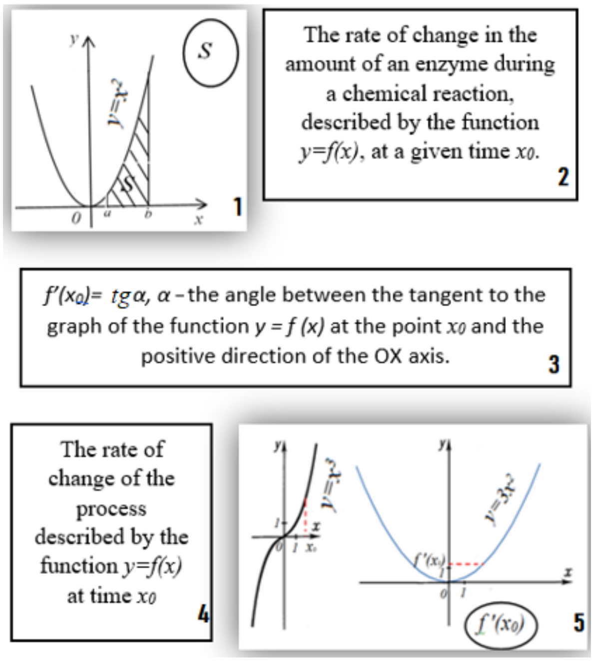


Fig. 3 Cards for Problem 1

- Problem 2. A material point moves in a straight line according to the law x(t)=t^2-12t-29 (where x is the distance from the reference point in meters, t is the time in seconds measured from the beginning of movement). Imagine that you are a material point model, and depict the change (in motion) of the projection of your speed on the x-axis with a time from 0 to 10 seconds.

The solution requires the establishment of the links between the characteristics (the value (speed at time t), the name (derivative of the function x(t) at point t_0), the meaning (number)), and different forms of representation of the value (verbal (the phrase "the speed at time t_0"); sign-oriented and symbolic (expression v(t) = 2t - 12); figurative and graphic (graph of the function v(t) = 2t - 12); tactile and kinaesthetic (movement of a school student with a certain speed from 0 to 10 seconds)).

3. Consideration of the Aspects of the SE of a School Student in the Teaching Process: Emotional and Value-Based, Substantive, Procedural, and Communicative Aspects

In order to activate the emotional and value-based aspect, the dependence of the students' comprehension of mathematical information on the duration of the lesson has been taken into account, and the instructional techniques developed by Podkhodova [27] have been used.

Attention should be paid to the development of the title and topic of the lesson. In addition to the topic of a lesson specified in the programme, it is not unreasonable to devise a name that is close to the child's experience and is able to provoke interest in order to evoke emotions, make them see the familiar aspects in a new material, i.e. to create conditions for fitting new information into the school student's experience and to prepare them for comprehension of new educational information.

In the learning process, the emotional state of the student should be taken into account. A teacher should not expect that a school student comes to a lesson with the right mindset. Students may have various problems (they may have quarrelled with someone, have been scolded by someone...), have a state of excitement, for example, after a physical education lesson, etc. The consideration of the emotional state of a child implies "inclusion" of the stage for "getting in the right mindset" for educational activities in the lesson. For that purpose, it is necessary to introduce such an additional stage into the structure of a lesson as the creation of an educational focus in the form of a task, a problem (solvable during the lesson), or a question. They allow a teacher to get a school student in the right mindset for a lesson, "to engage all areas of the school student's mental and emotional activity (feelings, memory, thinking)". Devising of the names and tasks for the creation of an educational focus are offered to the students at the beginning of a lesson, when, according to Souza [25], the students' comprehension is at a low level. Emotions have a significant energy potential and help to engage the students in the lesson. For example, when studying the numbering and calculation systems, the students are offered a task: "Examine the caricature of Jean Eiffel and its caption, which reads: "No prompting!". (Fig. 4) [28]. The students see that something in this picture was erased. They are offered to restore the missing parts and give an explanation for your answer.

The performance of this task for the creation of an educational focus leads up to the topic of the lesson, in particular, studying the Roman numbering system.

Fig. 4 Caricature by Jean Effel [28]

A positive attitude of the teacher is important in teaching. The teacher's behaviour in the classroom should provoke positive emotions, otherwise, a student can associate negative emotions with the content of the topic in mathematics, and the value-based orientations determine the student's attitude to the educational material.

It is recommended to take breaks for physical activity, including thematic ones. Physical activity breaks should be held in the middle of the lesson when there is a decline in comprehension. The physical activity break usually provokes emotions, hence an energy boost, thus, you should not be afraid that such a break will be a waste of time. An example of a thematic physical activity break may be the performance of tasks for the positioning of arms and legs perpendicular to the wall, ceiling, etc.

The substantive aspect of the SE is manifested in the method of development of inter-subject concepts [18].

The methods of manifestation of the procedural aspect are associated with consideration of the teaching styles, cognitive styles in the teaching process, both upon the organisation of teaching and the development of content [28]. Their development is based on the method of Betty Lou Leaver [29].

4. Correlation between the Real, Perceptual, and Scientific Mathematical Spaces in the Teaching Process

This correlation is partially achieved through the methods already mentioned. Moreover, when introducing new material in a situation where the SE contradicts scientific one, it is necessary to organise practical activities so that the ideas suitable for the introduced concept are formed therein, or to rely on the ideas from the SE that are suitable for the concept.

Another method for the manifestation of the interrelation of spaces is the solution of educational tasks. They are aimed at the development of generalised solution methods, at the generation of a mathematical model, contain a problem, have a space for discussion, contain ambiguity (hence they develop communicative abilities), carry educational information not only from the subject area, and require knowledge from various subject areas.

- Problem 3. What is the difference between the brother of Chernomor from the fairy tale of A.S. Pushkin "Ruslan and Lyudmila" and Thumbelina from the fairy tale of Hans Christian Andersen, and the ordinary people? (Chernomor's brother was a giant; his head was as big as a man.) Why, in your opinion, are there no people of such size?

It is advisable to consider this task when studying exponential functions. However, the solution thereof also requires knowledge of physics. In the event of an increase in the height and maintenance of the proportions, the bodyweight increases in proportion to the body volume, which increases in cubical relation to the linear dimensions of the body. As for the strength of the bone, it increases in proportion to the area of the cross-section thereof, which depends on the linear dimensions quadratically.

It is known that the strength of a human bone is 170 N/mm^2. In order to calculate the weight that a bone can withstand, it is necessary to multiply the strength by the cross-section area and divide the result by g (g = 9.8 N/kg). The human shinbone has a cross-section area of 2.8 cm^2. How much weight can it carry? (4,760 kg).

Let us assume that we increase the height of a person by a factor of 10. The weight will increase by 1,000 times. Thus, upon an increase in human growth by 10 times, the cross-section area of the shinbone will increase only by 100, i.e. the bone will become ten times less strong. The giant will simply not be able to stand on their feet since they will break. In order to avoid that, their cross-sectional area should be increased tenfold. The task to depict such a person will help to associate the information received and the students' ideas about people.

IV. Findings

The above-mentioned methods have been used in the process of teaching mathematics during the experiment in our study.

The study aimed to identify the influence of the proposed techniques and methods developed following the above-mentioned principles on the comprehension of educational material in mathematics.

A. Participants and Setting

The experiment involved 9 teachers and 256 students of the 10th grade: 114 of them were included in the control group, and 142 students in the experimental group. They had approximately the same average level of academic outcomes. The participants of the control group studied the topics "Derivative" and "Trigonometric Functions" according to the traditional methodology under the program. The participants of the experimental group studied the same topics with the use of techniques and specially designed tasks aimed at implementation of the holistic approach to teaching.

The final test containing tasks to identify the level of mastering of the topics studied was held on each of these topics to evaluate the results of the experiment in the control and experimental groups. Moreover, it included tasks involving real situations, in which it was necessary to develop a mathematical model of the situation (task 3 and task 5). The quality criterion for the assessment was the correctness of completion of the task.

B. Data Analysis

Table I shows the number of the students in the control and experimental groups who correctly completed each of the five tasks, as a percentage of the total number of the students in each group.

TABLE I
The Results of the Students' Test

Task no	Control group, %	Experimental group, %
1	86	91
2	84	88
3	63	87
4	56	82
5	23	78

The analysis of the differences in the frequency of occurrence of the quality criterion in the experimental and control groups with the use of the Pearson's x^2 criterion showed statistical significance at $p < 0,001$. Since the sum of the differences between the number of correctly completed task 3 and task 5 in the experimental and control groups is the largest, the difference in the results of the completion of these tasks characterising the presence of comprehension is significant.

When analysing the number of the tasks completed by each student, the average value across the groups was determined, and the reliability of quantitative differences in the control and experimental groups (p = 0.0001) was confirmed with the use of the Student's t criterion (Table II).

TABLE II
RELIABILITY OF THE DIFFERENCES IN THE INDEX OF QUANTITY OF THE COMPLETED TASKS IN THE CONTROL AND EXPERIMENTAL GROUPS

	Experimental group	Control group	t	p
Number of completed tasks	4.26 ± 1.53	3.13 ± 1.58	4.00	0.0001

V. CONCLUSIONS

The results obtained allow us to conclude that the school students in the experimental group: 1) have mastered the content of the topics "Derivative" and "Trigonometric Functions" and 2) have demonstrated comprehension of the educational material in mathematics at a significantly higher level. This means that the developed techniques and methods implementing the holistic approach contribute to the creation of conditions that ensure the understanding and comprehension of the educational material.

It should be noted that the results of mastering the topic "Derivative" turned out to be higher than that of the topic "Trigonometric Functions" in the experimental group. According to the results, the differences between the experimental and control groups were less pronounced upon assessment of the mastering of this topic. We believe that the reason for the revealed differences is the closer association between the topic "Derivative" and the real world. It provides more opportunities for the usage of the SE (not only from the field of mathematics) for demonstrating links between real, perceptual, and conceptual spaces. It also confirms the positive impact of developed techniques and methods of the holistic approach on the level of secondary school students' comprehension of the mathematical educational content.

The survey of secondary school students after the experiment also demonstrated an increase in the interest in studying mathematics, resulting in an increase in motivation.

We believe that the developed techniques will contribute to the growth of mathematical literacy. Its level is checked by the results of Pisa tasks. Pisa's tasks are distinguished by various ways of presenting information and links with the real world [30]. Task solutions require the establishment of relations between these ways of presenting information and creating a mathematical model. Techniques and methods developed are aimed at the formation of these skills.

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REFERENCES

[1] M. I. Rozhkov, L. V. Baiborodova, O. S. Grebenyuk and T. B. Grebenyuk *Pedagogika v 2 t. Tom 1. Obshchie osnovy pedagogiki. Teoriya obucheniya: uchebnik i praktikum dlya vuzov*. M.: Izdatel'stvo Yurait, 2020. https://studme.org/368817/pedagogika/tselostnyy_podhod_pedagogicheskim_yavleniyam
[2] *Filosofiya obrazovaniya dlya XXI veka* / Sbornik statei. - M.: Izd. Firma «Logos», 1992.
[3] M. I. D'yachenko and L. A. Kandybovich, *Psikhologicheskii slovar'-spravochnik*. Izd-vo AST, Kharvest. 2001.
[4] G. Frege, *Logika i logicheskaya semantika: Sbornik trudov*. M.: Aspekt Press, 2000.
[5] V. P. Zinchenko, *Psihologicheskaja pedagogika. Materialy k kursu lekcij*. Chast' 1. Zhivoe znanie. Samara: Samarskij Dom pechati, 1998.
[6] A. A. Brudnyj, *Psihologicheskaja germenevtika*. M.: Labirint, 1998
[7] G. Wiggins and J. McTighe. Alexandria, VA: Association for Supervision and Curriculum Development, 2005.
[8] I. V. Sapegina, Organizatsiya protsessa obucheniya matematike v 5-6 klassakh, orientirovannogo na ponimanie. dissertatsiya, kandidat pedagogicheskikh nauk RGPU im. A.I.Gertsena, 2002.
[9] M. E. Bershadskii, *Ponimanie kak pedagogicheskaya kategoriya:* (Monografiya), M.: Kaf. obrazovat. tekhnologii AGKiPRO,
[10] V. V. Znakov, *Ponimanie v poznanii i obshhenii*. Samara: SamGPU, 1998.
[11] M. Wertgejmer, *Produktivnoe myshlenie*. M.: Progress, 1987.
[12] S. Abramovich, A. Z. Grinshpan and D. L. Milligan, *Teaching Mathematics through Concept Motivation and Action Learning*. Hindawi Education Research International Volume, 2019.
[13] S. Asiedu-Addo and A. K. Arhin, "Connecting Mathematics To Real Life Problems: A Teaching Quality That Improves Students' Mathematics Interest (Translation Journals style)," *World Academy of Science, Engineering and Technology IOSR Journal of Research & Method in Education (IOSR-JRME)*, Volume 8, Issue 4 Ver. II, Jul. – Aug. 2018, pp 65-71.
[14] R. Skemp, *The Psichology of learning mathematics. Expanded American Edition.* Hillsdale, New Jersey, 1987.
[15] V. M. Turkina, "Vzaimosvjaz' ideal'noj i real'noj form znanija v obuchenii (na primere obuchenija matematike) (Translation Journals style)," *World Academy of Science, Engineering and Technology Nepreryvnoe obrazovanie: XXI vek*, vypusk 3 (23), 2018.
[16] N. S. Podkhodova and O. V. Sheremet'eva, "Logiko-psikhologicheskii podkhod k formirovaniyu matematicheskikh ponyatii v shkole. (Periodical style)," *World Academy of Science, Engineering and Technology Vestnik Pomorskogo universiteta. Seriya: Fiziologicheskie i psikhologo-pedagogicheskie nauki*. 2006, № 1, pp. 117-125.
[17] O. V. Sheremeteva and V. M. Turkina, "Problems of Mathematical Education of Primary School Teachers: Identifying Relationships between Concepts (Published Conference Proceedings style)," *World Academy of Science, Engineering and Technology Society, Integration, Education. Proceedings of the International Scientific Conference,2021,* Volume I, pp. 560-570.
[18] N. S. Podkhodova and O. A. Ivanova, "Problemy formirovaniya mezhpredmetnykh ponyatii pri izuchenii matematiki. (Translation Journals style)," *World Academy of Science, Engineering and Technology Pis'ma v Emissiya. Offlain. (TheEmissia. OfflainLetters): elektronnyi nauchnyi zhurnal.* 2013.
[19] I. S. Yakimanskaya, *Lichnostno-orientirovannoe obuchenie v sovremennoi shkole.* M.: Sentyabr', 2000.
[20] D. P. Resnick and L. B. Resnick, "Standards, Curriculum, and Performance: A Historical and Comparative Perspective (Periodical style)", *Educational Researcher,* 1985, volume 14, issue 4, pp. 5-20.
[21] I.S. Yakimanskaya, *Fundamentals of Personally Oriented Education.* M.: Binom, 2013.
[22] O.V. Sheremet'eva, "Preobrazovanie sub"ektnogo opyta studentov kak metodicheskaya zadacha podgotovki budushchikh uchitelei nachal'nykh klassov. (Periodical style)," *World Academy of Science, Engineering and Technology Izvestiya Rossiiskogo gosudarstvennogo pedagogicheskogo universiteta im. A.I. Gertsena,* 2008, № 66, pp. 329-337.
[23] T. Varghese, "Teaching mathematics with a holistic approach. (Translation Journals style)," *World Academy of Science, Engineering and Technology International Journal of Inclusive Education* 2009, 13(1), pp. 13-22.
[24] A. K. Osnitskii, *Struktura, soderzhanie i funktsii regulyatornogo opyta cheloveka*. M.: 2001.
[25] D. A. Sousa, *How the brain learns mathematics* (2nd ed.). Corwin Press, 2015.
[26] M. V. Soldaeva, "Realizatsiya tselostnogo podkhoda k obucheniyu

matematike kak uslovie dostizheniya ponimaniya. (Periodical style)," *World Academy of Science, Engineering and Technology Izvestiya RGPU im. A. I. Gertsena. Seriya Psikhologo-pedagogicheskie nauki,* 2013, № 161, pp. 202-206.

[27] N. S. Podkhodova, "Metametodicheskaya model' kul'turotvorcheskoi shkoly kak sredstvo realizatsii integratsiipri izuchenii matematiki (Translation Journals style)," *World Academy of Science, Engineering and Technology Pis'ma v Emissiya.Offlain. (TheEmissOfflineLetters): elektronnyi nauchnyi zhurnal,* ART 1416, Mai 2010.

[28] "*Metodika obucheniya matematike*: Kurs lektsii: uchebnoe posobie (Book style with paper title and editor)," N.S. Podkhodovoi and V. I. Snegurovoi, Ed. M.: Izdatel'stvo Yurait, 2019.

[29] B. L. Leaver, *Obuchenie vsego klassa.* M.: Novaja shkola, 1995.

[30] PISA for Development Assessment and Analytical Framework: Reading, Mathematics and Science, Preliminary Version, OECD Publishing, Paris. 2017. https://www.oecd.org/pisa/pisa-for-development/PISA-D-Assessment-and-Analytical-Framework-Ebook.pdf