Universal Journal of Educational Research 7(12): 2817-2829, 2019 http://www.hrpub.org
DOI: 10.13189/ujer.2019.071232

The Computational Activity of Younger Students: Neuropsychological Approach

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Received Ocotber 10, 2019; Revised November 12, 2019; Accepted November 20, 2019

Abstract The article is devoted to the research of computational activity of junior pupils taking into account their neuropsychological peculiarities. The place of computational activity in the system of higher mental functions is determined. It is shown that the necessary prerequisite for the development of higher mental functions is the aging of various brain structures. The following basic areas of the brain that are involved in the calculations are defined: occipital, parietal and frontal areas of the cerebral cortex. It has been established that various compositions of these zones are used to perform computations, which in turn influences the choice of methods of reasoning. It has been experimentally proven that in the process of computational activity, young learners apply different methods of computing to the same tasks.

Keywords Computational Activity, Arithmetical Actions, Junior Pupils, Neuropsychological Features, Higher Mental Functions, Cerebral Cortex, Brain Area

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1. Introduction

In the early 2000s, the European education community updated its work on defining the list of basic skills and sub skills needed by young people to live in a modern society. That was said in 2001 at the meeting of the European Council in Stockholm in the report "On Concrete Future Objectives of Education and Training Systems, 2001". Further discussion of the problem of basic skills and sub skills needed by young people to live in a modern society was held at the meeting of the European Council in Barcelona in 2002. It should be noted that among basic skills, along with reading and writing literacy, there is also computing, i.e. the computing skill, as indicated in the Communication from the European Commission to the European Council and the European Parliament "Efficiency and equity in European education and training systems" (Efficiency and Equity in European Education and Training Systems, September 8, 2006) [1].

At the same time, the countries of the European Union have actively participated in the study of the nature of key competences in order to effectively use them in the education systems of the Member States of the DeSeCo project. An important study in this area was the study 'Key Competencies. Developing Concept in General Compulsory Education', held in 2002 by the European Commission. In the report to this study, the key competences that a secondary school has to form are united into seven groups, with the ability to count down listed in the first group of key competencies [1].

Consequently, the reports indicate that computing competence and computing skill are recognized by the world community as the key, since a modern person, despite the availability of all kinds of electronic means, has to repeatedly perform oral calculations every day, analyze and evaluate the results of computing done with the help of gadgets, as well as to find a more rational way of reasoning. Computing competence manifests itself in the ability to perform qualitative computing, and its basis is the development of human computing skills and sub skills [2].

2. Materials and Methods

In order to develop a methodological system for the formation of computing skills in elementary school students, in 2012 we began a study consisting of theoretical and experimental stages. At the theoretical stage, we have studied the psychological, neurophysiological, and didactic literature on the problem of computational activity of younger students and teaching elementary school students to perform arithmetic actions of addition, subtraction, multiplication and division. At the experimental stage, we investigated the computational activity of elementary school students, taking into account the results of theoretical analysis of scientific research.

The basic concepts of our study are the concepts of computational activity and computing skills/subskills; therefore, within the theoretical stage of the study, we analyzed their interpretation in the psychological and didactic literature, as well as identified approaches to the formation of computing skills in elementary school students. We found out that the quality of computational activities determined by the development of cognitive functions, and the completeness of computing skills depends on the structural and functional development of the brain of the child. Therefore, the following theoretical study involved the study of the neurophysiological principles of computational activity and the identification of opportunities to improve the quality of computational activity of younger students. As part of the experimental study, we observed the computational activities of students while performing arithmetic actions of addition and subtraction with a transition through a digit within 100.

At the stage of theoretical research, we used the methods of theoretical analysis, systematization and generalization of research results of scientists, which allowed us to find out the psychological and neurophysiological nature of the phenomenon under study. At the experimental stage, we used the methods of observing the computational activity of students, interviews with them, and quantitative and qualitative analysis of the obtained experimental data.

The purpose of the article is to present the results of the experimental study of the computational activity of the pupils of the 2nd grade of elementary school at the implementation of addition and subtraction of numbers within 100, analysis of the results grounded on the data of neuroscience.

2.1. Computational Activity, Computing Skill and Sub Skill

Based on P. Halperin’s definition of activity as a process that is systematically or episodically restored by an “activist” and leads to a certain result [3], computing refers to a process that results in the execution of arithmetical actions between numbers. In elementary school of Ukraine, students learn the arithmetic actions of addition, subtraction, multiplication and division, so the computational activity of a junior student is aimed at finding the result of arithmetical actions of addition, subtraction, multiplication and division (entirely or with the remainder) of nonnegative numbers within a million.

In the works of psychologists J. Piaget [4], P. Halperin [5], N. Menchinskaya [6], V. Davydova [7] and N. Nepomnyashchaya [8], the complex process of formation of the concept of number and computational operations is presented in ontogenesis. This process in the early stages of child development is of visual-active character and reduces to the enumeration of elements in the space field. Then, the computational activity acquires a linguistic character, and at the next stage of formation, this function is carried out in an ideal plan. Speech acts, on the one hand, are means of expressing a complex system of knowledge, and on the other hand, the organizer of the computational activity. Gradually, operations that take place “in thought” are curtailed and replaced by abstract arithmetic thinking. Consequently, the actions and operations that carry out the computational activity are mental actions, which are the result of the transformation of external material actions with objects or their substitutes into the plan of perception, beliefs and concepts.

In our study, computing skills are understood as the ability to successfully perform computational activity as a result of the learned way of action, based on knowledge of its theoretical foundations and the skills of performing actions and operations that make up the calculation. The computing act is a system of operations, the successive execution of which allows a person to get the correct result in performing arithmetic operations. Based on the content of the computational activity, namely, the number of transactions it consists of, as well as variations of conditions, and as a consequence, the choice of a particular system of operations, we classify computing skills into simple and complicated. Simple skills include the successful performance of computational activity, which consists of a small number of actions / operations that do not provide variation conditions – branching. Complicated skills are characterized by more actions / operations and, depending on the fulfillment of a certain condition, provide a certain system of operations, i.e. contain branching. Simple skills in performing arithmetic operations are subject to automation, and can be executed by a person instantly, supposedly by the formula. Complicated skills consist of operations that need to be automated, i.e, learned at the sub skill level, and based on the variation of the conditions – branches, it is obvious that in general such a system of operations cannot be fully automated.

Confirmation of our position on the existence of simple and complicated computing skills we find in the works of the 2002 Nobel Prize winner D. Kaneman [9]. Describing the process of thinking, as that in which one conscious thought comes from another and is the result of brain work that produces an impression, premonition and helps to make a decision, the scientist examines the processes of fast and slow thinking. Fast thinking turns out to be a quick outcome with minimal mental effort, and slow – requires effort and order. According to the psychologist, to the fast thinking as a result of the formed sub skill belong oral calculations in the “Ten” concentric (simple skills according to our classification of computing skills). While written calculations, since they require effort and compliance with a certain order, the need to contain a lot of intermediate information in memory, D. Kaneman believes, are an example of slow thinking (complicated skills in our classification of computing sub skills) [9].

It has been several years since students – representatives of the digital generation – joined the elementary school. The development of their cognitive processes and metacognitive skills is influenced by the digital environment in which they are from an early age. Representatives of the digital generation have deteriorated memory, significantly reduced amount of attention, observed clips thinking, etc. As you know, the basis of cognitive processes is the human brain. Therefore, for the construction of effective teaching methods, in particular the formation of computing skills and sub skills, you need to know how the human brain functions when performing computational activities. Thus, one of the basics in designing and modeling the learning process should be the psychological and neurophysiological features of modern children, in our study – elementary school students.

2.2. Neuropsychological Bases of the Computational Activity of the Younger Learner

For successful computing, on the one hand, there should be readiness of brain structures, and on the other hand, demand from them. That is, in order to perform calculations, the child must develop certain areas of the brain involved in the computational activity, and on the other hand, computational activities develop these zones. The development of the brain of the child goes in two directions – the functional development and development of the neural apparatus (M. Bezrukykh) [10]. According to M. Bezrukykh [10], the most significant changes in the transformation of the neural apparatus occur in 5-6 years, and then in 9-10 years; from 5 to 6-7 years, there is a key reorganization of the morphological structure of the functional organization of the brain.

2.2.1. Cognitive Activity of the Younger Learner as the Basis of Computational Activity

In order to find out the ability of children to perform calculations, we resorted to a theoretical analysis of the cognitive activity of elementary school students in psychological and neuropsychological literature. The results of the study, systematization and synthesis of scientific sources are presented below.

Neurosciences have systems of brain regions that can participate in the computational activity that is formed in cognitive activity. Cognitive activity of a person is a conscious activity directed on the knowledge of the surrounding reality by means of mental processes of perception, thinking, memory, attention and speech. Therefore, we are interested in the age-old peculiarities of the course of cognitive processes in junior pupils, the basis of which is the ripening of certain areas of the brain. Let us turn to the data of neuroscience and age psychology.

Cognitive activity of a person rests on the joint work of an entire system of areas of the cerebral cortex, located at the boundary of the occipital, temporal and posterior-central cortex. The activity of these zones is necessary for the successful synthesis of visual information, for the transition from the level of direct visual synthesis to the level of symbolic processes, for operating systems of numbers and abstract relations. The harmonious work of these zones is necessary for the transformation of visual perception into abstract thinking, mediated by internal schemes and for preserving the gained experience in memory [11]. The temporal, parietal and occipital areas of the cerebral cortex provide the perception and processing of tactile, auditory and visual stimuli introduced into the memory system [12].

Population studies conducted at the Institute of Age Physiology of the Russian Academy of Sciences (RAS) under the leadership of M. Bezrukykh convincingly prove that at the junior school age, the brain system responsible for receiving and processing external stimuli passes to another level of functioning (Age Physiology): 1) at 6 y.o. there are changes in the organization of the system of perception; namely, conditions are created for in-depth perception of objects, operation of a large number of features; 2) some delay in the explanations seen, is due not to the primary deficit of visual perception, but to the slow selection of words; 3) children up to 6-7 y.o. show difficulty in perceiving and interpreting storylines, especially serial pictures. Processes associated with remembering occur on the combination of the temporal, frontal and with the involvement of the occipital part of the brain [13]. In the part of the brain called the hippocampus the integration of memories takes place, the understanding of the world (thinking, emotions) is the search system of memory [14]. Studies conducted under the leadership of M. Bezrukykh convincingly prove that at the junior school age there is a shift in the memory system to a different level – from the immediate memorization inherent in preschoolers, to memorization mediated by specific semantic tasks. And this requires the development of new methods of memorizing on the basis of comprehension of the material, rather than its formal repetition [10].

Reception, processing (coding) and synthesis of information obtained from various analyzers and apparatuses are provided by the temple, lower-parietal and frontal area of the cerebral cortex. These areas develop programs for the most complex behavior and control, including computing [11]. According to the data of the Institute of Age Physiology of the RAS, at 3-6 y.o., the formation of stable cognitive attention takes place, the number of features that are allocated increases, as well as the amount of attention; at 6-8 y.o., there is the formation of mechanisms of arbitrary electoral attention, while emotional involuntary attention is gradually replaced by arbitrary cognitive; at 7-8 y.o., unsatisfactory attention prevails, but unsatisfactory and arbitrary attention still has the features of immaturity, and, finally, at 9-10 y.o. unsatisfactory attention is organized on the type of adult (M. Bezrukykh). The focus of the child not only on the incentives that are directly attractive to him/her but also on the more abstract, disconnected characteristics of the environment, its information components observed. At the same time, up to 7-8 y.o., an arbitrary activity organized with the help of attention is easily pushed by activities that directly interest the child.

In the upper part of the brain, which is called the middle forefrontal bark, such complex mental processes as thinking, imagination and action planning [14] occur. Self-control and executive functions are provided by the part of the brain behind the forehead [15]. The prefrontal sections of the cerebral cortex are responsible for the ability of the person, making informed decisions, behaviour and skills [11, 14]. It should be noted that the prefrontal areas of the cerebral cortex ripen in the later stages of ontogenesis (at 4-8 y.o.) [11]; their development lasts up to 25 y.o. [13].

In the frontal areas of the cerebral cortex, there are complex syntheses of external and internal information that regulate, program, and control over the course of action, as well as decision-making in certain situations, especially when it is necessary to apply a certain method of action, in particular for calculations [11, 13, 16].

The results of the research conducted under the leadership of M. Bezrukykh show that although at 6-7, 9-10y.o. the mechanisms of selective attention and organization of activities are improved, it is only at the age of 9-10 that possible arbitrary, purposeful activity of the child takes place–the activity in which he/she can formulate the goal itself! Scientists observe problems with self-regulation in students of grades 1-3; at this age, the child badly regulates his/her own volitional efforts, because for this purpose the frontal areas of the cerebral cortex, which are formed up to 9- 10y.o., must be formed. The activity of the frontal sections of the brain involves the development of internal speech, which is accompanied by the child's thinking (L. Vygotsky, A. Leontiev, O. Luria) [11]. In the sections that are located in the area of the frontal lobes in front of the central gyrus at the border of the parietal, occipital and temporal parts, the information obtained is combined with emotions and memories, and there are complex analytical and synthetic mental functions that are responsible for thinking, decision-making and planning [13]. The parietal-temple-hind head zone becomes mature up to 8-12 y.o. and provides the development of speech, writing and computing [16]. The junior student's type of thinking is visual-imagery thinking, which is related to his/her emotional sphere; the basis of imagery thinking is visual perception, and the means – an image. Scientists observe the main feature of children's thinking – to perceive everything specifically, literally, not the formation of the ability to rise above the situation and understand its general and/or abstract content (M. Bezrukykh).

The studies have established that the left cerebral hemisphere is responsible for logical thinking and for the perception of the tables of addition and multiplication and reference schemes [14], and the parietal-occipital sections of the left hemisphere are involved in the perception of signs: numbers, signs of arithmetic actions, and auxiliary signs [11]. In the right brain hemisphere, emotional perception, which is associated with emotions that arose in the process of performing calculations (joy, success, satisfaction from achieving the goal), turns into memories in which the left hemisphere makes sense [14].

Scientists note the absence of a clear hemisphere specialization, which manifests itself in the nature of the brain providing for verbal activity. In adults, when solving the visually proposed verbal problem, functional associations of nerve centers involved in speech activity are localized in the left hemisphere. While in children of 7-8 y.o., the structures of both hemispheres are generally and uniformly involved in this process. Up to 9-10 y.o., with increased involvement of frontal areas speech processes become more selective. Language is the basis of thinking of the child. Features of speech activity at the junior school age determine the specifics of mental operations. For 7-8 y.o. imagery thinking is typical; it is based on the achievement of a certain degree of maturity of visual perception, and the means of such thinking is an image. With the development of mechanisms of speech activity, the child acquires the ability to allocate with the help of verbal-logical thinking the essential characteristics of objects and phenomena hidden from direct perception. Therefore, at the younger school age, the functional abilities of the child significantly increase [10].

Thus, in terms of structural and functional development of the brain of the child, elementary school students are ready to master the concept of number and to acquire computing skills.

2.2.2. Neuropsychological Principles of Computational Activity

Today scientists know some areas of the brain responsible for certain functions, including for calculations. But, at the same time, one must understand that in the normal conditions, when solving any problem, the entire brain works, and the combination of brain sections when solving the same problem can be quite different in different people (Swab Dick, A. Semenovich, T. Chernigovskaya). Consequently, it is impossible to state that mathematical activity, in particular computing, is provided by the functioning of the left hemisphere of the brain only. While performing any task or solving mathematical problems, the whole human brain works!

For complex intellectual functions, there are no "centers" that would produce them, but in the implementation of each of them, certain parts of the brain play a particularly significant role. Particularly important for intellectual activity are the particles of the third frontal lobe, the lower parietal and partly temple, since their damage gives the most serious violations of higher mental functions. Proceeding from the fact that in solving the computational problem the whole human brain works, we are still interested in the question of which zones, blocks of the brain can participate in computational activity. There are studies of the correspondence of certain areas of the brain to the performance of certain functions, including computations, but these zones, brain sections, are established in the presence of violations in their execution (O. Luria, L. Tsvetkova, A. Semenovich, S. Kotiagina, E. Grishina, T. Gogberashvili).

The persistent difficulty in mastering reading, writing, and counting T. Akhutina relates to the development of the operation of programming, regulation and control of arbitrary actions performed by the frontal parts of the brain (prefrontal cortex, frontal lobe); the processing of auditory and kinesthetic information relates to the activation of the temple and parietal sections, mainly the left hemisphere; operations of processing of visual and visual-spatial information are realized mainly by the back of the right hemisphere (parietal lobe) [17].

A more detailed look at the neuropsychological structure of the intellectual activity of computing in younger school age is suggested by A. Davidovich [17], which is developed on the basis of the analysis of characteristic difficulties of mastering the concept of number and numerical operations of first-graders with neuropsychological syndromes in development that deviates from the norm.

The visual recognition of the digits is due to the work of the visual area of the cortex of the occipital part, the auditory – due to the functioning of the auditory center of the cortex, which is localized in the upper temple lobe. The analysis of the composition of the number and its digit structure, as well as understanding of arithmetic signs are provided by the divisions of the right hemisphere; and the retention in the short-term memory of the material, which is necessary for performing the calculations, is provided by a wide temporal zone. Recognition of digits and the implementation of computations are carried out with the participation of memory and require a certain concentration of attention. The solving of the simplest mathematical problems occurs under the control of the frontal cortex sections responsible for the ability to perceive abstract concepts and to carry out targeted activities. In particular, the orientation, planning, implementation and control of the execution of the computing operation are carried out by the frontal zones of the frontal lobe, and the transition from one operation to another, by the hind lobe sections.

The work of the occipital lobe of the cerebral cortex is connected with visual perception; occipital-temple sections are responsible for the processing of visual information; intraparietal frustum – for comparative analysis and calculations; parietal sections – for the processing of spatial information. These two areas are associated with prefrontal cortex, which is responsible for leadership functions, attention, cognitive activity, and motor skills [19].

Consequently, computing is a complex multilevel process of the higher human nervous activity. Scientists at Stanford University have established that in the human brain there is a special center of computing, which is localized at the joint of the parietal and occipital lobes of the dominant hemisphere. However, this center of computing is closely connected with other areas of the cortex, without which it cannot fully function. Proceeding from the fact that various computational systems are used in the computational activity – optical, spatial, somato-spatial, locomotive, etc., then the brain's basis of computation is the joint work of the occipital, parietal and frontal sections of the brain, which we will call 'the system of brain sections that provide computational activity' [19].

Thus, some difficulties younger students face in performing calculations are neuropsychological in nature, and knowing the causes of these difficulties will allow to find effective corrective measures.

When choosing a method for computing skills formation, it should be taken into account that different people use different brain zones to perform the same higher mental functions, in particular, the implementation of computations [20]. Thus, studies by Swab Dick found that for oral calculations the Chinese use slightly different areas than those that are used by English-speaking people of the Western world. Both groups use Arabic numerals for calculations; however, English-speaking people in the processing of numbers are more likely to use language systems, while the Chinese are turning to visual-motor systems more quickly. This is due to the fact that the Chinese are learning graphic signs from birth [21]. Perhaps this fact explains why mental arithmetic in Ukraine, which is quite effective in the east, does not give good results in the formation of computing skills.

Besides, according to D. Medina – a molecular biologist-evolutionist who is engaged in the problems of brain development and the genetics of mental disorders, director of the Center for Brain Research at Pacific Seattle University, head of the Department of Bioengineering Medical School at the University of Washington – whatever functions are not attributed to individual parts of the brain, there are no two people with the same brain organization, who solve the problem equally and treat it in the same way at the sensory level. Scientists have discovered 14 separate sections that are responsible for various aspects of human intelligence scattered throughout the brain, like cognitive magic dust. These sections form the basis of the theory of P-FIT (Parietal-Frontal Integration Theory). When the P-FIT sections were observed during the depression of a person in meditation, different people used a variety of combinations of these sections to solve complex problems [15].

In general, any higher mental function, including computing, is provided by the integrative activity of the entire brain. In the process of development of a child and as a result of his/her exercises, functional structure of the process changes, and the formation of activities at subsequent stages can rely on an already existing system of collaboratively working zones [11]. Proceeding from the fact that calculations belong to higher mental functions, they are complex functional systems and cannot be localized in the narrow zones of cortex, but should cover complex systems of collaboratively working zones, each of which contributes to the implementation of complex mental processes and which can be located in different parts of the brain [11]. D. Kaneman holds the same opinion and notes that there is no specific section in the brain in which all computational activity would be concentrated [9]. This thesis is based on the concept of the systemic structure of complex psychological processes suggested by O. Luria, in accordance with which each form of conscious activity is always a complex functional system and is based on the joint work of the three blocks of the brain: energy – regulation of tone and wakefulness; receiving, processing and storing information; programming, regulating and controlling complex forms of activity; each of these blocks contributes a lot to the implementation of the mental process as a whole [11].

2.3. The Results of the Study of Computational Activity of Addition and Subtraction within a Hundred of Second Grade Learners

Basic theses of the research:

- Individual differences in solving problems

When solving one and the same problem, in different people different areas of the brain are involved (D. Medina).

- Child development

The functional structure of the process changes and the formation of activities at the next stages can be based on an already existing system of jointly working zones of the brain (M. Bezrukykh).

- Computational Activity.

Integrative activity of jointly working areas, each of which contributes to the implementation of complex mental processes and which can be located in different parts of the brain.

We were interested in how these concepts of neuroscience are manifested in the computational activity of elementary school students.

Based on the first thesis, before the start of the experiment, we understood that different students would not choose the same calculation methods as convenient.

We also assumed that students' preferences on calculation methods may vary at different stages of learning. And, the main thesis for us is that the whole brain of a child works when performing calculations. On the one hand, to perform the calculations, the necessary condition is a certain development of the occipital, parietal and frontal lobes of the brain (in violation of which the child suffers from various types of dyscalculia), and on the other hand, other areas of the brain are also involved in performing computational activities.

According to the research of the Japanese scientist Kawashima, who recorded the work of the human brain on a tomograph during calculations with a transition through a dozen within 20 without fixing and fixing the time for completing tasks, the inclusion of the conditions for performing calculations at a speed activates a larger number of brain zones. Thus, we can assume that the student's good computing skills indicate the development of his/her brain as a whole.

With the aim of establishment of peculiarities of computational activity, we studied 60 learners of the 2nd grade of the Ivano-Frankivsk 3-level school 11 with intensive teaching of English (Ukraine). At the preparation stage, we examined class journals and interviewed teachers to find out how successful in mathematics their learners were. First, we studied the grades in mathematics of students in these classes and calculated the mean (2-A – 8,8; 2-B – 9,3; 2-C– 9,4), and we also analyzed the products of students' activity – separate tasks from the control paper – checking them against correctness criterion which concerned the execution of calculations within 100 without going through a period and calculated the coefficient of performance – the ratio of correctly found results to the total number of tasks (2-A – 0,6; 2-B – 0,7; 2-C – 0,8). Secondly, in the course of the conversation with the teachers, we were interested in the quality of the computing activity of the students of the class, namely the opportunity to provide complete and correct explanations of the actions performed, the use of one or more methods of reasoning, the likes of the students in the choice of computing, the speed of calculations, the independence in performing calculations. In the course of the conversation, teachers noted that the students mostly use bit-by-bit addition and subtraction techniques; most students immediately write the answer without resorting to explanations, but at the request of the teacher, explain the actions performed; by this stage, almost all students complete and subtract numbers within 100 quickly and correctly.

According to the results of the analysis of class journals and conversations with the teachers of the four 2nd grade classes, we selected two classes: 2-B and 2-C, as those who according to the average indicators of success in performing arithmetic actions of addition and subtraction within 100 without going through a period are approximately at the same level as the other class. It was the students of those two classes who participated in the following study.

At the main stage of the experiment, we observed the computing activity of the learners, as well as interviewed them. The schoolchildren were offered the task "To calculate the viral in the perfect way for you, commenting every step of the computing: 64 + 17, 38 – 26, 45 + 34, 55 – 38”. The photos of some of the students’ works are shown below (Figure 1.)

The third-year students of the specialty 013 “Elemantary education” of Vasyl Stefanyk Precarpathian National University conducted the research. Two students worked with every learner: one interviewed the learner, and the other kept the minutes, taking note of the questions, the learner’s answers and the time spent on solving the problem, as well as explanations.

The evaluation of the results was carried out against the following criteria: the correctness of the calculations; the time spent on the computing; the method chosen for the computing, the completeness and reasonableness of explanations, variability – possibility to use another way of computing. The results are demonstrated on the diagrams below.

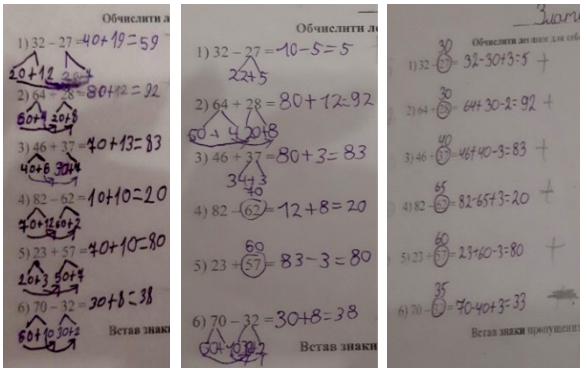


Figure 1. Samples of students’ works

Diagram (Figure 2.) presents the distribution of learners according to the correctness of the calculations. The results obtained are the following: 21 learners (35%) solved the problem without any mistakes; 26 learners (43.3%) made 1 mistake; 13 learners (21.7%) made 2 or more errors (among them 3 schoolchildren (5%) made mistakes in all the problems) (in Figure 2.). The mistakes were of the following nature: when adding with the transition through a period, decomposition into convenient addends was done wrongly; when subtracting through a period with the use of period subtraction from the result of calculation with the dozen of numbers, learners subtracted the result of calculation with the units of the numbers; occasional mistakes made when adding and subtracting with no transition through a period.

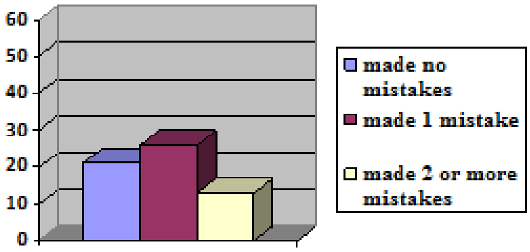


Figure 2. The distribution of learners according to the correctness of the calculations

According to the time spent on the computing, we got the following distribution of the learners: 3-5 min. – 19 learners (31.7 %), 6-8 min. – 32 learners (53.3 %), 8-10 min. – 9 learners (15 %); the results are demonstrated in the diagram above (Figure 3.).

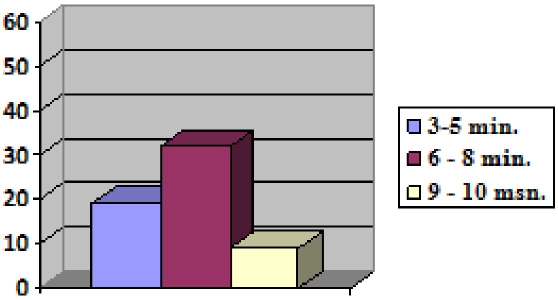


Figure 3. The distribution of learners according to the time spent on the computing

Of the known computing methods (rounding; addition / subtraction through a period; addition / subtraction to / from the number of the sum; addition / subtraction of the sum to / from the number), the most commonly used methods were addition / subtraction through a period (17 learners – 28.3%) and rounding (12 pupils – 20%). The other 31 students (51.7%) used different methods (addition / subtraction through a period, rounding, subtraction from the number of the sum, subtraction from the sum of the number) (Figure 4.)

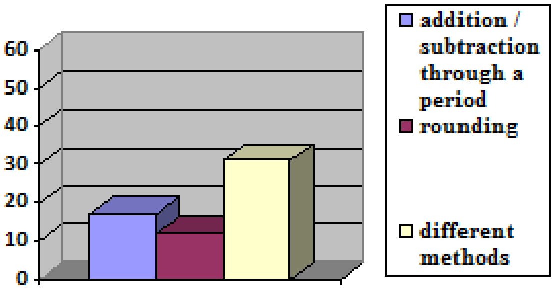


Figure 4. The distribution of learners by choice computing methods

By doing the computing, the learners explained the course of their reasoning. It should be noted that only a part – 15% (9 students) demonstrated literate mathematical speech, and the explanations of 56.7% (34 students) did not show clarity, although they followed the logical sequence of operations; 28% (17 students) did the action correctly but their reasoning was not expounded; they did not explain the course of reasoning. On request to explain the progress of the computing, individual students experienced difficulties in selecting the desired words and used schemes for explanation. The results of the study of the learners according to this criterion are presented in Diagram (Figure 5.).

The next criterion was variability, that is, the student’s ability to switch to another way of reasoning, using another method of computing. 31 learners (51.7%) showed their ability to perform calculations in a number of ways, justifying the feasibility of their use; 17 students (28.4%) showed awareness of different methods of computing but had some difficulties in choosing another method and in implementing it; 12 pupils (20%) did not find it possible to use another way of reasoning (Figure 6.).

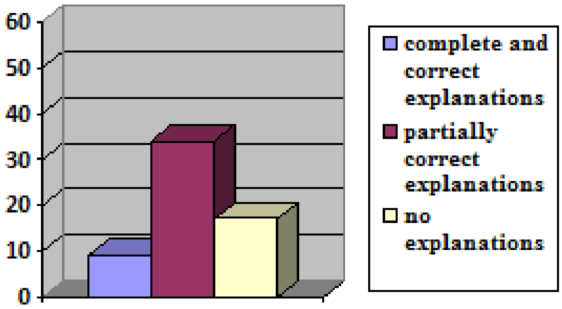


Figure 5. The distribution of learners according of to the completeness of explanations of the computing

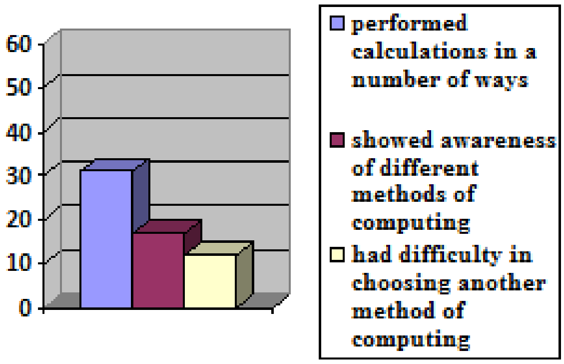
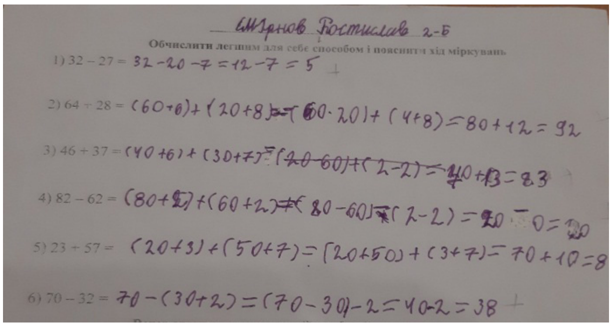


Figure 6. The distribution of students according to the ability to switch to another method of computing

3. Discussion

The results of our study correlate with the results of the neuropsychologist L. Tsvetkova, who considers addition and subtraction through a period very difficult actions. The complexity of computing can be explained by the fact that such calculations can be done only indirectly, including a number of additional ways. In this case, computing becomes a mental activity, which includes in its structure several consecutive operations based on the knowledge of the digit structure of the number, the ability to appropriately replace the number with the sum, perform intermediate operations, and store interim results in the operating memory. Moreover, all these actions should take place on the basis of a stable overall program of activities. In operations of subtraction, an important factor is the preservation of spatial representations that allow the subject to set in the intermediate operations the desired direction of computing, which is expressed in addition or subtracting intermediate results. For example, when subtracting 18 from 46 in some cases it is necessary to subtract an intermediate result (subtraction by parts based on the rule of subtracting the sum from the number), and in others – add it (the way of rounding, which is based on the dependence of the difference from the change of the subtrahend) [19].

It was this kind of mistakes that we observed in students' calculations (Figure 7), and it is obvious that they are related to the certain functional defects of the individual brain areas that provide computational activity.



Ширнов Ростислав 2-Б

Обчислити легшим для себе способом і пояснити хід міркувань

1) 32 – 27 = 32 - 20 - 7 = 12 - 7 = 5

2) 64 + 28 = (60+6)+(20+8)=(60·20)+(4+8)=80+12=92

3) 46 + 37 = (40+6)+(30+7)= ~~(20-60)+(2-2)=~~ 70+13=83

4) 82 – 62 = (80+2)+(60+2)=(80-60)+(2-2)=20-0=20

5) 23 + 57 = (20+3)+(50+7)=(20+50)+(3+7)=70+10=8

6) 70 – 32 = 70-(30+2)=(70-30)-2=40-2=38

Figure 7. Sample of a student's work

Based on the data of neurophysiology when performing addition and subtraction within 100, a complex of sections of the brain are used, namely (Figure 8): those responsible for perception (occipital and temple sections), processing of visual and auditory information (occipital, temple and parietal sections), memorization (occipital, temp leand frontal lobe), analytical-synthetic thinking (occipital, temple, parietal sections and frontal lobe), decision making and planning (occipital, parietal sections and frontal lobe), self-control over execution and executive functions and internal speech (prefrontal cortex).

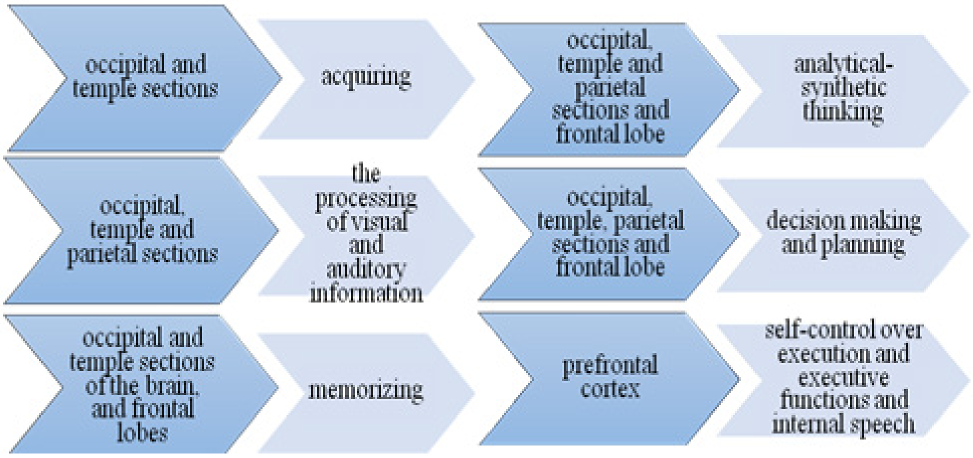


Figure 8. A complex of sections of the brain when performing addition and subtraction within 100

Consequently, as a result of the analysis of the correctness of the calculations, we can indirectly judge if these areas of the brain function according to the age. Thus, in 35% of the students the occipital, temple and parietal sections of the brain, as well as frontal lobe and the forefront cortex, in the complex, function effectively for the performance of computing activity; 43.3% of students who made one error in calculations have some deficiencies related to the functioning of the prefrontal cortex, which is responsible for self-control of calculations, executive functions and internal speech; 13 students (21.7%) who made two or more mistakes may have defects in the functioning of the occipital, temple and parietal areas of the brain, frontal lobes, as well as prefrontal cortex that provide memory, analytical and synthetic thinking, decision making and activity planning, self-monitoring of calculations and executive functions; and 5% of students may experience some impairment, even with underdevelopment or injury of certain areas of the brain. So, we have 18% of students who have disadvantages in computational activity.

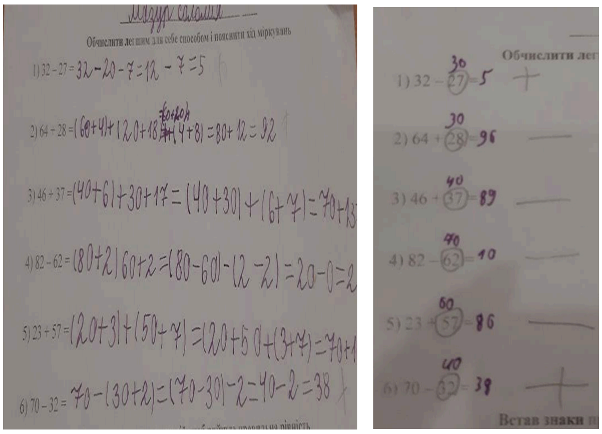
Such a percentage distribution is fully consistent with the results of T. Ivanova's research, who found that about 10-20% of children experience difficulties in computational activity [22]. In general, according to T. Ermolova, V. Ponomareva and N. Florova, from 3 to 13% of the population experience difficulties in learning arithmetic (in particular in the computational activity) from childhood; and 20% of people have a low ability to master mathematics [23]

In the group of learners who have correctly completed all the tasks, the computing lasted from 4 to 7 minutes, which is explained by the fact that the students reasonably approached the tasks, even when all the operations that compose the calculation were mastered, they all resorted to expounded considerations, as demanded by the researcher; in addition, they were ready to use different computing techniques. From this, we can indirectly conclude that the front-cortex, which is responsible for self-control, executive functions, regulation and internal speech of the child, at this age – 7-8 years – is actively developing, which allows the student to consciously choose the computation method and follow a particular algorithm. It was interesting to note that in a group of learners who had made 2 or more errors, there were cases of very fast completion of tasks. This indicates superficiality, unreasonableness and unconsciousness of the mental activity, which may be due to the developmental delay in the pre-frontal cortex and frontal lobes of the brain.

For cases of adding and subtracting numbers with the transition through a period (64 + 17, 55 – 38), learners could apply the following computing methods: addition / subtraction through a period; addition / subtraction by parts; addition / subtraction based on the rule of adding / subtracting the number to / from the sum; addition and subtraction by rounding. The distribution of students by choice of the most convenient method for computing is shown in Diagram 4.

Most learners – 28,3% (17 students) chose the method of addition / subtraction through a period, since it consists of simpler actions by structure. This suggests that, although the frontal lobes of the brain are actively developing at this age, yet their potential is not sufficient for self-regulation, building a plan of action that should provide logical considerations, as in the case of using the method of rounding when the learner adds / subtracts not a number on condition, but a close to it round number, and then, understanding the dependence of the result of addition / subtraction on the change of one of the addends / subtrahends, on the contrary, subtracts / adds the difference between the round number and the number that was to be added / subtracted. The method of rounding for cases of addition and subtraction of two-digit numbers with the transition through a period was chosen by 12 students (20%). We are satisfied with this result, because it indicates the quality of the processes of analysis, synthesis, planning and self-control, which are particularly influenced by the development of the pre-frontal cortex and frontal lobes of the brain. To the question "Why did you choose exactly this way?" the learners answered: "So I'll do this calculation faster," "I like this way more", "When I calculate this way, I make fewer errors, or I'm not mistaken at all", "I use it in my everyday life", "In this case, it is better to use this very method". The learners' answers to the asked questions showed emotions (positive and negative), which depended on the success or failure of applying a particular computing method.

The next criterion was the completeness and reasonableness of learners' explanations. When evaluating the completeness of explanations, account was taken of the student's pronunciation of all operations that comprise the action of the computing, the literacy of mathematical speech, the logical sequence of the performed operations and their reasonableness. For example, calculating the value of the sum of numbers 64 and 17, their reasoning was as follows: 1) "I write down the first addend 64 in the form of the sum of period addends 60 and 4; 2) I write down the second addend 17 in the form of the sum of the period addends 10 and 7; 3) I add dozens to dozens: 60 + 10 = 70; 4) I add units to units: 4 + 7 = 11; 5) I add the results obtained: 70 + 11 = 81." At the same time, in the case of addition through a period, 15% of the learners (9 students) demonstrated the wrong solutions, with errors occurring at the stage of adding single-digit numbers with a transition through a period. Individual students recorded only intermediate results (record in a chain) and submitted the result. Most of the respondents illustrated the intermediate results schematically and with the help of visual images (showing the split into period and convenient addends with the help of arrows; the rounding method was illustrated by circling a certain component), which indicated the formation of imagery thinking but not the formation of sections of the brain that are responsible for the analytical-synthetic thinking (in fig.9).


Мазур Саломія
Обчислити легшим для себе способом і пояснити хід міркувань
1) 32 – 27 = 32-20-7=12-7=5
2) 64 + 28 = (60+4)+(20+18 =(60+20)+(4+8)=80+12=92
3) 46 + 37 = (40+6)+30+17=(40+30)+(6+7)=70+13
4) 82 – 62 = (80+2) 60+2=(80-60)-(2-2)=20-0=2
5) 23 + 57 = (20+3)+(50+7)=(20+50)+(3+7)=70+1
6) 70 – 32 = 70-(30+2)=(70-30)-2=40-2=38

Обчислити лег
1) 32 – 27 = 5 (30)
2) 64 + 28 = 96 (30)
3) 46 + 37 = 89 (40)
4) 82 – 62 = 10 (70)
5) 23 + 57 = 86 (60)
6) 70 – 32 = 39 (40)
Встав знаки

Figure 9. Sample of a student's work

It should be noted that only 15% of the subjects demonstrated literate mathematical speech, and the explanation of 56.7% of them did not differ in clarity, although they adhered to the logical sequence of operations; 28% of the subjects performed the action correctly, but their reasoning was not deployed, they did not explain the operations performed. At the request of the researcher to explain the course of performing the calculation, individual students had difficulty in selecting the right words and used a scheme for explanation. This situation indicates that the temple-parietal-occipital sections of the brain have not yet been formed and the visual-imagery thinking is present, which is connected with the emotional sphere.

The next criterion was variability, that is, the student's ability to switch to another way of thinking, using a different method of calculation. For example, from 51.7% of the learners who chose the method of addition and subtraction through a period, 23.3% (14 students), at the request of the researcher to perform computing in other ways, suggested the solution with the help of adding by parts; 28.4% (17 students) – by the rounding method, which indirectly indicates the good functioning of the occipital, parietal and frontal lobe sections of the brain in the process of the computing activity.

Consequently, a larger number of pupils in order to perform calculations use, depending on the practicability, different methods of computing and different interpretations of their explanations (verbal and visual), and the set of convenient methods of computing in children is different. Such results showed the presence of individual neurophysiologic differences of the interviewed children.

Concern was caused by 5% of learners who made mistakes in all the tasks but could neither explain the implementation of actions nor justify the choice of steps in calculations. In our opinion, this indicates a disadvantage in the functioning of certain areas of the brain (the interior of the parietal section of left hemisphere, which is responsible for quantitative evaluation) and may be the result of operating dyscalculia.

In the context of the interpretation of the causes of problems encountered by younger students in the process of computational activity, the conclusions we made, which are based on the analysis of experimental data obtained and on the basis of neurophysiologists, correlate with the results of the study of A. Davidovich, who in 2004-2005conducted the experiment in the first grades of secondary school № 22 in Minsk (three classes). The methodology of the experiment was based on the classical method of psychological activity by A. Luria, adapted for children of preschool and primary school age by E. Simennytska [18], supplemented with tests for understanding the logical and grammatical constructions by A. Semenovich, as well as the method of studying the concept of number and its period structure and counting operations at the initial stage of training using a set of methods by L. Tsvetkova, which in turn was based on modern neuropsychological and general psychological concepts of formation, development and decay of higher mental functions in children [24].

The research methodology of A. Davidovich consisted of eight groups of tests: "Simple calculations", "Reading of digits and numbers", "Comparison of numbers", "Writing a dictation of simple and complex numbers", "Period structure of number", "Finding a digit in a period grid" and also as in our experiment – "Arithmetic actions of addition and subtraction", and besides this "Optical perception of digits and numbers". Just like in our experiment, at the second stage of the empirical study A. Davidovich used assignments for the study of knowledge and skills in mathematics in children enrolled in the first grade of secondary school, compiled in accordance with the normative requirements for knowledge, skills and sub skills of first-graders of secondary school.

In the empirical study by A. Davidovich, as well as in our study, all the students of the first three classes of the secondary school took part. She studied 63 children (32 girls and 31 boys) at 6-7 years of age to find out characteristic difficulties of mastering the concept of number and counting operations by first-graders with various neuropsychological syndromes of developmental disorders. First-graders with functional lack of formation of the frontal parts of the brain (6 children) demonstrated a violation of the counting as targeted selective activity. The nature of the difficulties in understanding the concept of number and counting operations by first-graders with a functional lack of formation of the left temple section (4 children) is associated with a lack of phonemic hearing: there is insufficient support for the system of differentiated verbal connections and their strong traces, which is required for the implementation of counting operations. The nature of the difficulties in understanding the concept of number and counting operations by first-graders with the functional lack of interhemispheric interactions of the transcortical level (5 children) is associated with the appearance of elementary and systemic reversals in them. First-graders with functional lack of formation of the right hemisphere of the brain (13 children) demonstrate difficulties in assimilating the period structure of the number and the dependence of the quantitative essence on it. First-graders with functional deficiency of subcortical brain formations (15 children) did not demonstrate any specific difficulties in mastering the concept of number and counting operations. The general picture of statistical data was affected by the insufficiency of background components of mental activity: exhaustion, increased distractibility. First-graders with functional deficiency of the stem formations of the brain pulp (8 children) demonstrated difficult-to-correct violations of both the operational and background components of the intellectual activity of counting [18]. In addition, children with atypical development (4 of them) were made into a separate group, and the Norm group (8 children) was the control group [24].

The analysis of difficulties conducted by the researcher sheds more light on the prerequisites for computational activity, which are the formation and adequate functioning of certain areas of the human brain. In quantitative terms we can also see correlation of the data obtained by A. Davidovich with the results of our study. So, if we take into account the fact that 15 children with functional deficiency of subcortical brain formations did not find problems in computational activity and 8 children of Norm group, then we have about the same percentage – 36.5% of children who have no difficulties in the study of A. Davidovich and 35% of younger students who performed the calculations correctly in our experiment. But at the same time, there are some differences in the number of students who in the study by A. Davidovich found difficult-to-correct violations of both operational components and background components of the intellectual activity of the counting (12.7%), and who in our study showed incorrect solutions in each calculation (5%). Though both results fall in the range of 3 to 13% of the population, which has difficulty in learning arithmetic, in particular in the computational activity, as noted in the research of T. Yermolova, V. Ponomareva, and N. Florova [23].

4. Conclusions

For learning, including the development of computing skills, the child's brain readiness is needed, i.e. it requires that certain areas of the brain that are involved in cognitive activities be mature. However, there is also a reciprocal link – learning contributes to the development of the brain, namely the development of those areas that are involved in solving a math problem. Thus, computing activity, on the one hand, requires a certain level of development of the complex of brain sections of the student – occipital, parietal and frontal lobes, and on the other hand – activates these areas of the brain.

At the same time, one must realize that the frontal areas of the brain are formed up to 10-11 y.o., therefore younger schoolchildren may have problems with planning of activity, control over its course, self-regulation, which negatively affects the quality of the computing activity. In addition, we consider important the thesis of neurophysiologists that the dispersion of individual differences among elementary school students may be up to two years. This means that one learner can demonstrate, for example, analytical-synthetic skills already in elementary school, and another, even in middle school, will dominantly use imagery thinking. However, normative documents of primary education require the achievement of certain results, among which – the formation of computing skills. In addition, from 3 to 13% of people have difficulty in computing. Proceeding from this, experts in the didactics of mathematics are tasked with the development of such methods of teaching computing activity, which will allow achieving normative results. Therefore, in the process of forming computing skills, it is necessary to take into account the advice of neuroscientists specializing in the correction of the problems of the functioning of certain brain sections involved in calculations.

So, we find relevant the advice of L. Tsvetkova, a student of A. Luria, on the most optimal teaching methods that lead to a sustainable restorative effect of the method, which allows a learner to reproduce in an expanded form the internal structure of the computing activity by taking outside individual operations, the successive execution of which can lead to the performance of the computing activity.

Written in the desired sequence operations will make a program that manages the outside of the course of the restoration of the impaired action and allows you to control this course [19]. Dividing an action into a series of successive operations enables the learner, even in the presence of violations in certain areas of the brain, to perform computing activities already at the very beginning of training. To the syllabi created in a restorative education, it is necessary to put forward a number of requirements: selectivity in the content of the program, the sequence in the implementation of operations, multiple repetitions of the program in the student's learning process, the support of external supplementary aids. All this creates conditions for a high degree of activity and independence of the student in overcoming defects [19].This idea is fully in line with the requirements for the formation of mental actions, which ensure the efficiency of the formation of skills and abilities suggested by L. Friedman [26], and with the training according to the theory of phased formation of mental actions offered by P. Halperin [27]. According to which, in the first stages of teaching, the student is provided with a complete and correct orientation of the action – its plan, the algorithm. Then, the action is performed in a material form with objects, or in a materialized form – with their substitutes, expanded with the fixation of all its components. When the students have mastered the composition of the method of computing with the help of external regulators – memos and/or reference notes, and are able to explain the performed operations aloud, the action is performed in the form of external speech as fully expanded. At the next stage, the learner begins to skip auxiliary operations, calling out only the main ones – the action goes into the form of a loud speech to oneself. And, finally, the action is minimized and automated; it is performed as if by the formula in the mental plane. If to follow these steps when computing, we can expect that the teacher will achieve the goal, even in the case of minor violations of the functioning of learners' certain brain sections. Thus, one can expect that the percentage of students who make many errors in calculations will significantly decrease.

The results of the study of the computing activity of learners of the 2nd grade, which testify to the use of different methods of calculation by students, confirm the practicability and necessity of forming different methods of computing in elementary school learners. Even the method of rounding, which requires a certain level of development of analytical and synthetic activity, and therefore the maturity of the occipital, parietal and frontal lobe areas of the brain that are not well developed in all children under the age of 7-8, it is advisable to introduce and teach students computation by rounding one of the addends or subtrahends. This position is consistent with the thesis of specialists in neuroscience that the brain develops only when a person solves a new and complicated task for himself.

The prospects for further research we see in the development of a methodology for the formation of computing skills in elementary school students based on the consideration of neurophysiological features of modern children in order to correct defects in the course of cognitive processes and stimulate the development of certain sections of the brain.

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