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Peculiar Features of Verbal Formulations in School Mathematics

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I. Introduction

To exteriorize the contents of school mathematics various semiotic and symbolic means are used [11], [12]. They allow of fixing - in the expanded or minimized form - the gist of separate objects of assimilation: certain concepts, mathematical facts (axioms, theorems, formulas, etc.), modes of activity (rules, algorithms, method of solving problems and proving mathematical statements) as well as their integrity - a fragment of a systematic scientific theory.

The text (from the Latin *textus* – tissue, texture, and web) is the most important way of the expanded reification of mathematical content formed by means of natural language. Being reflected in the text the essence of concept, mathematical fact or mode of activity as well as scientific knowledge about their system acquires semiotic-symbolic reality of life. It is the shell of the text through which the content analysis of scientific and academic noesis is made. Textbooks, manuals, tutorials and other media represent texts in their visual modality. In their aural modality the texts are delivered by the teacher in the classroom or by the speaker in audio, visual, and virtual modes of learning.

Since the concept of "text" covers two different aspects of the language fixation of mathematical content - at the level of individual object assimilation and at the level of system of knowledge, one should distinguish between these cases by entering two different terms into circulation. In the first case, when the text reflects the essence of a particular object of assimilation, it is appropriate to use the term "object-based (oriented) text". In the second case, when the text is a discrete part of a scientific theory, namely - a theme from the school course of mathematics, it is appropriate to use the term "instructional text". It is clear that an educational text may contain one or more object-based texts as its components.

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II. Types of Object-Based Texts

In the school course of mathematics the object-based texts are:

- For concepts – *formulations* of various types of definitions and concept *descriptions* which are a verbal fixation of the results (or the progress and results) of certain concept disclosure techniques application;
- For math facts - *formulation* of axioms, theorems, properties, characteristics and *descriptions* (verbal equivalents) formulas, correlations, etc;
- For mathematical operations - the formulation of rules, algorithms, heuristic schemes and unstructured descriptions of the methods of proving mathematical statements, the ways of mathematical problems solving and more.

III. The Specificity of the Wording

The logical structure of the formulation depends on the type and characteristics of the object of learning, the essence of which it captures. In its turn, the logical structure of the formulation defines the stylistic design of the corresponding object-based text.

a) *The formulations of definitions*

We consider it right to differentiate between strict and lax formulations. A strict formulation is a logically structured and stylistically perfect text that is constructed according to certain rules of logics and natural language. A strict formulation is devoid of redundancies and expressive content, it is concise and meaningful, its every word being an important text component. Stylistic modifications are allowed, but limited in number. A lax formulation (a correct wording made by the pupils in their own words) can be not logically structured and stylistically imperfect. In the instructional process such kind of formulation has certain didactic functions, both – at the stage of the assimilation object introduction and at the other stages of its mastery by the students. In our opinion, didactically balanced use of lax wording along with the strict wording should be institutionalized in school practice.

i. *The structure of the strict wording of the definition*

General logical structure of a strict formulation of the concept definition reflects the signified concept, a generic term, species differences, and the relationship between them [7]. It can be represented by the following scheme:

the signified concept → generic term → species differences.

However, the text which is the wording of the definition in its certain stylistic modification can be built in different ways, by inductive as well as deductive principle. In the first case, the text reflects the verbal passage from the particular to the general, and in the second case – vice versa. For example, in textbooks, manuals, tutorials on the methods of teaching mathematics, and reference books [1], [3], [9] the following definitions of the term "Rhombus" can be found:

"A Rhombus is a Parallelogram in which all sides are equal";

"A Rhombus is a Parallelogram with four equal sides, like a square that's leaning";

"A Parallelogram, in which all sides are equal, is called a Rhombus";

"If all sides of a Parallelogram are equal, a Parallelogram is called a Rhombus".

The first two formulations of the definition of a Rhombus directly reflect the logical structure of a general definition of the concept, thus reflecting inductive reasoning - from the signified concept to the generic concept. Therefore, they should be called *inductive formulations of concepts definitions*. The third and the fourth formulations of the rhombus definition also meet the general logical structure of the concept definition, but reflect a different mental progress, which is fundamentally different from the previous one. Here deductive reasoning follows the principle - from the generic concept, the content of which is separated by some specific features of the signified concept, to the signified concept as a subspecies of the generic concept. This suggests that general logical structure is indirectly reproduced in such definition and relevant texts may be called *deductive formulations of concepts definitions*.

ii. *Content identical definitions*

In the definition of a rhombus the contents of the texts match as the rhombus is defined through the same generic shape - a parallelogram and they employ the same specific properties - the equality of all sides of a parallelogram. However, semiotic-symbolic components of these object-oriented texts are different - the wordings of the above definitions do not match the form of text construction. We can say that in this case the inductive and deductive formulations of the concept definition are identical in their content but semiotically different. Hence, they are to be considered to be various semiotic-symbolic means of the concept essence reification.

iii. *Content-different definitions*

It is not only semiotically different but content-different definitions of the same concept which are used in school mathematics. If, for example, the concept of rhombus is determined through a generic term "rectangle" and the related specific properties, then we will have a semantically different definition. It is clear that semiotic-symbolic components of content-different definitions can differ, although the relevant object-oriented text can be built the same way - by inductive or deductive principle.

Thus, different notions of school math can be exteriorized with the help of several semiotic-symbolic means which are text-definitions formed by means of natural language. Fluency in these semiotic-symbolic means should be considered as one of the parameters of a formed concept.

iv. *Methods that replace or supplement the concept defining procedure*

In cases when the essential features of the concept have not been sufficiently studied or there is no particular need to do it, one of six techniques that complement or replace the definition are used. These include [7, p. 356]: a) pointing at the object, b) explanation – the disclosure of the concept through the etymology of its name, c) description – the disclosure of the nature through examples, d) characteristics – concentrating on characteristic features, properties, concepts, and e) comparison – disclosure of the concept through its comparison with other concepts e) distinction – disclosure of this concept through the properties of a contradictory notion.

The progress and the results of the use of such methods of definition are fixed in descriptive texts. They are fundamentally different from texts-definitions both - in their structure which is often not clearly marked, and in their contextual and semiotic-symbolic components. Thus, in teaching mathematics descriptive texts appear as specific semiotic-symbolic means.

b) *Formulation of mathematical facts*

In the dictionary of logical terms [7] the notion of "fact" (from the Latin *faktum - done, what is done*) is defined as real, actually existing, non-fictional phenomenon or event, something what actually happened, theoretical basis for generalization and conclusion. Mathematical facts that are taught in high school mathematics include axioms, theorems, and formulas. School mathematics is not a strict deductive theory, although it also has content elements which are constructed deductively and the idea of axiomatic construction of mathematics is supported in it.

Those classes of math facts, which are the theorems in deductive theory, in the school course are divided into at least three groups.

The key facts that are most important for the deployment of the logic of the course and teaching high school students mathematical operations are established as a result of the proof. These facts are usually called theorems, although it is not necessarily that this term is used to designate them. For example, the signs of divisibility are not called theorems.

Some basic math facts are introduced into school math without proof. In this case, the students are said that the proofs of such facts exist as they are, but their consideration for one reason or another is postponed. For example, in school basic algebra properties of functions are introduced without proof, and in the geometry course almost all formulas of the volume of geometric bodies are introduced without proof.

Students can encounter some properties of mathematical objects and their attributes in the process of solving problems. These auxiliary facts are usually provided a situational meaning. Students are not required to memorize them. Basic math facts are usually placed in the theoretical part of the tutorial. For students it is them which are the main targets of assimilation.

i. *Common and different features in the definitions of concepts and formulations of mathematical facts*

Object-based text containing formulations of axioms, theorems, properties, characteristics, and so on have both common and different concepts with texts-definitions. Common properties are displayed at the component level - the formulations of mathematical facts are also contextual and semiotic-symbolic components that are subject to certain logical structure. A semiotic-symbolic component - the possibility to exteriorize the meaning of mathematical facts through various text shells - is common.

The features which are different are generated not only through a diversity of objects that describe the formulation of definitions of concepts and formulation of mathematical facts. From the standpoint of semiotic approach the most significant difference we see is that the texts-formulations of mathematical facts may reflect some of the information about the object both openly and covertly.

ii. *Peculiarities of covert information in the formulation of a mathematical fact.*

In the formulation of mathematical facts (axioms, theorems, formulas, etc.) covert information can be of three kinds.

Covert information of the first type

Covert information of the first type is present in each formulation of mathematical facts taught in school mathematics. It is associated with an indirect reflection of the so-called explanatory mathematical fact. The illuminative part of the theorem is a set of objects from which the subset, the elements of which have to do with the conclusion of the theorem, is differentiated.

In each theorem that defines equality or similarity of triangles an illuminative part is a set of pairs of triangles, rather than any other their number. In this set the focus is made on a subset of such pairs of triangles in which the sides and corners are in some relations which are specified in the theorem. Thus, according to the third premise of the signs of equality of triangles in this subset each pair of triangles must have respectively equal sides. It is for these pairs of triangles - the elements of this subset, that the conclusion of the theorem in which the relations of equality are made is established.

Covert information of the second type

Information of the second kind becomes covert when a mathematical formulation of the fact is categorical (affirmative) in its construction. It's the matter of common knowledge that each mathematical fact contains premise and conclusion. They are related to each other either by the relation of implication "If A..., then B..." or by the relation of equivalence "If A..., then B... and if B...then A..." when the mathematical fact maintains certain criteria (necessary and sufficient conditions) [3], [10].

The text membrane of the fact which has an expanded linear structure has a form of an implication. Typically, it contains the words "if", "then" which serve as specific signs and specific punctuation marks allowing of separating the text of the premise from the text of the conclusion of theorem. Moreover, the text of the premise precedes the text of the conclusion. For example, in textbooks every sign-theorem of equality or similarity of triangles has this type of formulation. *The text membrane of the fact which has an unexpanded nonlinear structure* also has a form of an implication. But in this case the text of the premise follows the text of the conclusion and concerning the two words "if" and "then" the first one is usually present and it fully performs the functions of them both. An example of this type of text is the formulation of the third sign of the equality of triangles: "The triangles are equal if their corresponding sides are equal". A categorical (confirming) form of the formulation can be *called a textual semi-expanded shell of the mathematical fact*. It does not contain sign-words "if", "then", the conclusion of the fact has an expanded form and the premise has a minimized form as a rule. Here lies veiled information of the second type. Its recognition largely depends on what type of the verbal structure of the fact - linear or nonlinear, is realized in the text.

For example, a categorical formulation of the theorem about vertical angles "Vertical angles are equal" is the text of the linear type where the premise of the theorem precedes the conclusion. However, the identification of covert information, particularly about where exactly the premise of this theorem lies is quite difficult for the students.

It turns out that most of the theorems the categorical formulations of which are based on a linear type, present more difficulties for the students when deploying the premise than those theorems, the text shells of which have a non-linear type [12]. The fact is that the linguistic peculiarities of the nonlinear type object-based text mostly require the use of reverse designs, otherwise, most categorical formulations of nonlinear type will transform into inverse formulations. Additionally, the use of inverse structures in the formulations leads to a particular semantic distinction of premise and conclusion of the mathematical fact which facilitates their detection.

For example, the affirmative formulation of the divisibility properties of number 10 can be built as a text of a nonlinear type. In particular, it can acquire the following formulation: "The number with “0” as the last digit in its record can be divided into 10”," "The number with the record ending in “0” can be divided into 10”. There is hidden information of the second type in both formulations. It’s much harder to remove it from the first text than from the second.

Covert information of the third type

The fact that the information is covert is permeated by a categorical (affirmative) structure of the formulation of mathematical facts. We associate its essence with the convolute meanings which appear in interpreting the terminology used in the text. For example, in the premise of the Pythagorean Theorem firstly a subset of right-angled triangles is distinguished from the set of triangles, and secondly it is implicitly stated that one side of the triangle has a length which is longer than the lengths of its two other sides. In the conclusion of this theorem there has been fixed the existence of the dependence among the lengths of the sides of the triangle, but not among any of its other elements. In addition, the conclusion reveals the formal meaning of the dependence of the length of the longest side of the triangle on the lengths of its two other sides.

Just as texts-definitions, texts-formulations of mathematical facts which have differences in content and semiotic-symbolic components should be considered to be different semiotic-symbolic means, even when they are identically built. For example, semiotic-symbolic components of the listed properties of divisibility of a number by 10, though built on a non-linear type, differ significantly, thus, these object texts are different semiotic-symbolic means. A categorical formulation of the Divisibility by 10, which is also a sample of a non-linear text - "Those and only those numbers ending with a zero are divided by 10", is different in its content from the formulated properties, and thus it is also a certain semiotic-symbolic means. So, math facts from the school course of mathematics, as well as the concepts of this course may be openly exteriorized by several semiotic-symbolic means, which are text formulations formed by means of natural language. The fluency of operating these semiotic-symbolic means should be one of the indicators of the mathematical fact assimilation.

iii. *Shells of mathematical formulas*

It is not only formulas that can be used to fix the expanded language content of mathematical formulas but also the object-based texts- descriptions. For example, a verbal analogue of the formula of the square of the sum of two numbers is: "Square of the sum of two numbers is the sum of the squares and twice the product of the given numbers” can be considered the formulation. However, reorganizing it in a less concise text and putting separate semantic units of the text in different sentences, we get a text-description of this formula. Here is an example: “The formula of the square of the sum of two numbers asserts the equality of two expressions. The first expression reflects the symbolic record of the square of the sum of two numbers. The second expression symbolically reflects the result of raising the sum of two numbers to a square. The second expression has three terms the square of the first term, twice the product of the first and second numbers and the square of the second number”.

c) *The structure of the text-description of mathematical facts*

Texts-descriptions of mathematical facts also have contextual and semiotic- symbolic components. Understanding of such texts is largely dependent on the structural features of its iconic and symbolic component. In most cases this component comprises two parts - confirming and explanatory ones. The explanations, with the help of which the hidden meanings are ejected and placed the necessary emphasis on, make the text-description of the formula a rather powerful didactic tool. It is clear that the semiotic-symbolic component of the text-description may be realized in different ways with one and the same semantic component. As a result, each object-based text will act as a separate language semiotic-symbolic means.

d) *Formulations of the methods of operations*

In a general sense a method of operation is a system of consecutive activities and operations, the implementation of which results in an outcome that meets the aims of the operation and is adequate. Methods are the most fundamental types of operation that come from the knowledge of the most general laws of objective reality and specific patterns of an object, phenomenon, and the process under research [7]. To indicate those types of operations that are more specific and are used for different specific purposes the term "way" is used. For example, in the methodology of teaching mathematics they distinguish: general methods of mathematics (axiomatic or deductive reasoning, equations and inequalities, coordinate, vector, etc.), methods of proving mathematical statements in which the deductive method is used, methods for solving certain class of problems (a method of the variables substitution in solving biquadratics, a method of using an auxiliary element in geometric problems, etc.). All these ways of operations are the objects of assimilation into the school course of mathematics.

In the structure of the ways of operation they differentiate content (epistemological) and operational (activity-based) components. The content component of the way of operation is a system of knowledge which includes: initial knowledge about the object and its properties, the final knowledge of the results of operations with the object, knowledge of the operating mode of activities (actions and operations which in a definite sequence realize the way of operation), knowledge of subject-practical means needed to perform the activity, the guidance system of the choice of some ways of operation among the others. The operating component of the operation mode associated with the direct performance of its actions.

The acquisition of the semantic component of the way of operations by the students is characterized by such new constructions in their personal experience as knowledge, and mastery of the operational component is reflected in skills.

i. *Structure of the operation way formulation*

The wording of the rules, algorithms, and heuristic schemes in school mathematics are also contextual and semiotic-symbolic components that are subject to certain logical structure. In general terms, it can be represented as:

the object → operations with the object → the result.

The deployment of this scheme in the text of formulation can occur both in the linear and nonlinear modes. If the text has a linear structure it describes the actions with the object and then – the obtained result. If the text has a nonlinear structure everything is done vice versa.

Most of the rules, algorithms, and heuristic schemes of school mathematics which are the open objects of learning have a nonlinear structure. For example:

- To divide fractions the dividend should be multiplied by the number inverse of the divisor [14];
- To solve the system of equations through a substitution method, you should:

1) express one variable of any of its equations through the other;
2) substitute this variable by the resulting expression in a different equation of the system;
3) solve a created equation with one variable;
4) find the corresponding meaning of the second variable [1].

ii. *Specificity of non-linear texts*

Object-based texts of the non-linear type are implicative. In these texts the operations with the object are separated from the result these actions will arrive at. The operations and the result are connected by consecutive relations though the cause and the consequence in a nonlinear text are reflected in inverse order. Such texts are devoid of the words “if", “then” with their functions being performed by the phrases: "in order to ... you are to ... ", "to… one should…” and so on. However, every rule of the school mathematics can be formulated in a purely implicative form. For example, the rule of fractions division in this case may look as follows: "If this fraction is multiplied by the number which is inverse to the other number, we get a share of the division of this fraction by this second number".

With the same semantic component, different text shells of the rule, such as the rule of dividing fractions, act as different semiotic-symbolic means.

iii. *Peculiarities of the linear type texts*

Linear formulations of operation types are rare in school textbooks. For the most part, formulations of operation types are categorical. The formulations of the rule of multiplying two fractions (mathematics tutorial for the 6th form) is the text of this very kind: “The product of two fractions is a fraction, the numerator of which is the product of the numerator and the denominator is the product of the denominators” [8].

This fractions multiplication rule can be interpreted as a mathematical formulation of the appropriate fact. It depends on what meaning – that of the result or the procedure is given to the word “product”. In a procedural sense in this text it means the operation of finding the product of two fractions, and hence the first part of the text, “the product of two fractions is …” carries the meaning “if we multiply two fractions, the product is obtained as the result of the following steps ...". It is in this case that the given text will act as the formulation of the multiplication of fractions. If we understand the word “product” in the resulting sense, then the formulation becomes affirmative which is a sign of the mathematical fact formulation.

Thus, the same text shell can cover the contents of different objects of assimilation. It is clear that with different content components, although with the same semiotic- symbolic components of such texts, they represent different semiotic-symbolic means.

e) *Non-verbalized rules of the application of definitions and formulations*

In studying mathematical concepts and facts the non-verbalized rules of their use serve as implicit objects of assimilation as the correct performance of the relevant operations even without them being verbalized is an indicator that the content of a concept or fact has been mastered by the students.

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Let's consider the definition of the concept of a standard form monomial provided in the algebra tutorial [1]. "If the monomial has only one numerical multiplier which is put in the first place and if each variable is included into only one factor, such monomial is called a standard form monomial". From this definition follows the following rule of the reduction of the monomials to the standard form:

"To reduce the monomial to a standard view, you are:

1) to multiply numerical factors;
2) to place the resulting number first in the record of standard monomials;
3) to group the multipliers that contain the same variable;
4) to find the product of similar alphabetic factors in each group using the rule of multiplication of powers;
5) in the record of a standard monomial to place the derived products of monomials after a numerical factor and in alphabetical order".

In such expanded form the rule of the monomial reduction is not offered to be learnt by school children. The main object of assimilation is the relevant definition. However, the index of conscious understanding and mastering of this definition is not only the ability to reproduce the wording of the definition, but the ability to perform correctly the above mentioned sequence of operations. It does not matter whether the student can verbalize the meaning of the actions performed. The very fact of the correct performance of operations is of importance here. Thus, each object-based text containing definitions of the notion and the formulations of the theorem, properties, attributes, and formulas should be considered in two ways - affirmative and procedural. Hence, in every object-based text except semantic and semiotic-symbolic components one should see a functional component that will influence the variation of the corresponding semiotic-symbolic means of external fixation of mathematical content.

f) Texts-descriptions of ways of operation

Texts-descriptions used for the expanded content reification of the content of the ways of mathematical operations differ from the texts-formulations by their unstructured semiotic-symbolic component. For example, the following text contains the information about the rule of finding the ratio of two numbers in a non-structured way: "In mathematics there is a convenient way of comparison of similar quantities, which is that to compare quantities they seek an answer to the question, how many times one quantity is larger than another. The answer to this question is found by dividing" [8].

For the most part, by means of unstructured texts the content of the methods of proving mathematical statements, means of solving problems, and more is fixed. Like similar text shells of mathematical facts, they have two parts - confirming and explanatory ones. The texts of the descriptions will vary depending on how their semiotic-symbolic components are built: whether a confirming part is represented explicitly, how transparently the explanatory part explicates the necessary core content, on what basis - inductive or deductive - the text-description is built. However, any variations will present a new semiotic-symbolic means of reification of the same method of operation content.

IV. Conclusions

Educational function of teaching mathematics as a major feature of modern school mathematics education lies in it that students should master a certain amount of social experience and human knowledge which will help them discover and develop their cognitive and human potentialities, needs, interests, and facilitate their self-actualization.

The content of school mathematics education as an abstraction and its reification by semiotic-symbolic means in different modalities (visual, auditory, and kinesthetic) requires from the students learning school mathematics, to grasp a several semiotic-symbolic systems in full volume and at a certain level. It also demands special knowledge and skills to transfer one semiotic-symbolic system into another, including the transfer of visual, tangible assets or plastic substitutes into a verbal system and vice versa.

Some semiotic-symbolic system, including some subsystems of mathematical language should be a means of students' further education and development, and therefore should be regarded as objects of assimilation in teaching and learning mathematics in school.

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