

Operations of classification thinking in students working on verbal tasks

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Abstract

Modern science features a contradiction in the study of classification features proper to thinking in children and adolescents, as well as a lack of knowledge about its features in educated adults). The authors have developed and tested a new experimental method for detecting the functioning of a number of logic operations classes on verbal material. The experiment involved university students majoring in mathematics (n=217 of the logic of classes as isolated, but they rarely use them as a means of solving classification problems on the verbal material. We have also found that the students use various operations with logic of classes with different degrees of success. The article can be used to assess the ability and readiness of future teachers to identify and put into practice the purposes of logical thinking formation in students.

Keywords: mathematical education, classification thinking in adults, the operations with logic of classes, relations of community, classification problems, theoretical thinking.

1. Introduction

1.1 Relevance of the subject

The development of thinking and its correlation with age, sociocultural environment and education is a traditional psychological problem. Remaining a relevant issue, it has been covered in various areas of research (Artemyeva, 2013; Clayton & Overton, 1976; Kemp, 2012; Saalbach & Imai, 2012; Sabirova & Zakirova, 2015; Vlasova, Kirilova & Sabirova, 2015). The extent to which educated adults use thinking subordinated to the rules of formal logic (or its common forms) in problem solving has so far been insufficiently investigated. Scientists note and study only the significant differences, for example, between the mathematical method of reasoning and the everyday reasoning or the distortion of the former under the influence of the latter (Vinner, 1997, 2011). This also applies to the classification thinking: the operation of its higher form, based on the logic of classes, has not been adequately studied yet. There is no data how university students of advanced mathematics use the logic of classes in the implementation and evaluation of operations performed on the material of everyday language. Accordingly, it is unknown whether students training for a career in teaching mathematics are prepared to raise the culture of classification thinking in students at primary and secondary levels (Vygotsky, 1962; Muthivhi, 2012; Nigmatov, 2015).

1.2 Problem statement

Classification thinking is usually studied in psychology as a set of operations of comparison, generalization, and classification. Tasks for performing similar operations on verbal and non-verbal material are included into a large number of intelligence tests for children and adults (Anastasi & Urbina, 1997; Mackintosh, 2011; Flynn & James, 2012; Wasserman & John, 2012; Kaufman & Alan, 2009).

The operations of classification thinking have been studied in psychology from various theoretical standpoints. In Jean Piaget's genetic theory of intelligence the operations of comparison and classification are very important components for research; with a focus on the stages of their development from early childhood to adolescence (Piaget, 1951). The proper scientific forms of thinking appears in adolescence. These forms are characterized by the ability to perform formal operations on special symbolic material, e.g. on mathematical symbols. These formal operations can be carried out not only on real objects, their images and names, but on operations themselves. The emergence of scientific thinking in adolescents determines the maturation of the relevant structures rather than the content of training (Inhelder & Piaget, 1958, 1964).

The study of classification occupies an important place in the cultural and historical theory of L.S. Vygotsky (1962). The development of verbal thinking is connected with the way of word-building generalization which builds the meaning of the word. Early forms of thinking in children – syncretes and complexes – have a different structure than those in adults and do not conform to the standards of formal logic. The highest form of generalization achieved by preschoolers is the so-called conventional concepts. The level of classification thinking required by scientific concepts appears only at school age in the process of studying scientific disciplines. According to L.S. Vygotsky, the most

important characteristic of scientific thinking is the discovery of common features beyond the concepts included into a hierarchical classification system. Scientific thinking takes place only on the basis of the concepts within any scientific discipline. In situations of everyday life, adults with a scientific thinking continue to use it in the form of everyday concepts.

A.R. Luria (1976) experimentally confirmed L.S. Vygotsky's ideas that the emergence of certain logical operations is not associated with age, but rather with the mastery of scientific disciplines in the process of schooling. He investigated the peculiarities of thinking among the illiterate rural people in the regions where the traditional way of life is preserved. The battery had a lot of tests on comparing and grouping objects and their images. Traditional examinees (the term introduced by P. Tulviste (1987)) understood the similarity as belonging to a common practical situation of use. If the proposed objects did not belong to the common practical situation or had no formal resemblance, it became difficult for the examinees to solve the problem. It is well-known that students and adults who received a systematic education solve comparison problems through general class inclusion. Luria's studies showed that even adults, if unschooled, never use these logical operations.

For modern consciousness, a standard norm is mastering a certain level of classification thinking. This emphasizes a clinical and psychological approach to the study of thinking. When execution of operations deviates from the norm, it can be a diagnostic criterion of pathologies in affective sphere or in thinking (Van Rijbergen & Kok, 2015; Tvardovskaya, 2014).

P. Tulviste built on the heritage of cross-cultural studies of thinking began by L.S. Vygotsky and A.R. Luria. He identified the specific content of scientific knowledge, which is directly responsible for the formation of logical operations. The systems of scientific concepts are built on these logical rules. While studying various scientific disciplines, a student also develops logical knowledge as the knowledge of thinking. Due to this, a student begins to distinguish two different ways to assess judgments in solving problems: their assessment as true/false, on the one hand, and logically correct/ logically incorrect, on the other. Thus, P. Tulviste claims that it is not substantive content of scientific knowledge and concepts, but the meta-subject (i.e. formal-logical) component that plays the key role in the development of classification thinking.

In the process of education at school (primary, secondary or higher) the learner (student) can acquire formal logical knowledge in two ways. He can receive it intuitively simultaneously with different scientific disciplines. Another way is to study it as an individual discipline, for example, as part of courses in formal logic or mathematical logic. Realizing the importance of logical knowledge, the authors of modern textbooks include this content into various disciplines at both secondary and primary school. A number of new methods have been developed to help gifted children learn the elements of the logic of classes at the stage of preschool education. This has changed the scientific view of the age when mastering classification thinking becomes possible. However, the question about the direction and criteria of its development in adults is still important to answer.

The team under the leadership of J. Bruner (Bruner & Olver, 1966) proposed its own criteria of age dynamics of comparing individuals aged 0-19. The development of comparison is presented as a change in the grouping criteria. During the transition to adolescence and youth, in the process of defining their similarities/differences the examinees begin to use functional features instead of sensual. The authors do not analyze comparison by means of inclusion into class (classes) with names that already exist in language. The second indicator of development – the improvement of logical form of comparison - is reduced to elimination of complexes. The mental operations of 19-year-old college students are regarded as the result and upper limit of this development. The features of thinking in children and adolescents are discussed from this perspective. The authors agree with L.S. Vygotsky on the decisive role of education in the development of thinking. However, the theoretical background and experimental procedure of this study do not allow us to determine the direction and criteria for further development of classification thinking in adulthood. The question about the relationship of this development and training in higher professional school remains open as well.

The concept of V.V. Davydov (1996) helps determine the specificity of the development of classification thinking in adults. While pursuing a cultural and historical approach, he put forward a new understanding of scientific thinking and identified its two types - scientific-empirical and theoretical. L.S. Vygotsky saw the key criterion of scientific concepts in their systemic and hierarchical organization. V.V. Davydov believed these signs are crucial only for scientific-empirical way of thinking, which underpins the classification systems in many branches of science - botany, zoology, geology, etc. Scientific-theoretical concepts more fully reflect the quality features of scientific thinking. Theoretical thought can be defined as "thinking about thinking", scientific concepts themselves being its subject. V.V. Davydov considers the formation of operations and procedures of theoretical thinking the most important objective of modern education.

This concept forms the basis of the experimental practice of teaching where the foundations of theoretical thinking arise as early as in elementary school. The result of secondary and higher education should be the ability to apply theoretical thinking to different material. The theoretical level of classification thinking is based on the concepts of the logic of classes. The logic of classes is included into courses of formal logic; mathematics majors study it at university as part of mathematical logic. Mathematicians implement the operations of the logic of classes on specific signs. However, it remains still unclear to what extent the logic of classes is a universal characteristic of classification thinking in students. Also, it is not obvious how much willingness to implement the norms of the logic of classes is shaped by the material

that provokes everyday ways of thinking. This posed the *problem* of our empirical research. We suppose that the extent to which the logic of classes converts the classification thinking in students and becomes a universal way of solving relevant tasks can vary greatly. Verifying this assumption was the *objective* of this work.

Specific methodological tools are necessary for this research: a special type of mental problems, experimental procedure and criteria for analyzing its outcomes. We started from the concept developed by V.V. Davydov (1996), who believed that the ability to perfect tools of our thought should be an important outcome of modern education. It is theoretical thinking that makes it possible. Implementing and building on this approach, we consider that mastering the standards of comparison cannot be an indicator of classification thinking development sufficient for educated adults. Classification thinking on theoretical level is necessary to solve the tasks where the objects of analysis are logical operations themselves. If there is a need to evaluate, compare and improve the results of the operations performed by the examinee or someone else, such analysis should be based on the system of concepts of logic classes. Similarity is the criterion for measuring and comparing the results of solving various problems connected with logic classes. A degree of similarity is the volume of class and a number of signs that constitute the content of the concept (the name of the class). It is the assessment and improvement based on the logic of classes performed prior to logical operations that constitutes a mental act corresponding to the theoretical level of classification thinking. This position became the basis for the development of experimental procedures and mental problems that can trigger students' acts of classification as theoretical thinking and help explore it experimentally.

2. Methods

2.1 Data collection methods

For our study, we modified the method of forming groups of equivalence on verbal material. The original method comprised two subtests, each of them including 14 tasks for comparison (7 to find similarities, and 7 to identify differences) of the expanding group of words. The stimulus material of the 1st subtest is presented by the words 'banana', 'peach', 'potato', 'meat', 'milk', 'water', 'air', 'bacteria', and 'stone'. The first question is "How are a banana and a peach alike?", the second is "How do a banana and a peach differ from a potato?", the third is "How are a banana, a peach and a potato alike?" and so on. The word range in the 2nd subtest is 'handbell', 'horn', 'radio', 'telephone', 'newspaper', 'book', 'picture', 'learning', and 'embarrassment'. Almost all tasks have multiple correct solutions. The difficulty of comparison increases with the extension of the group of words.

The purpose of modification is to complete the procedure with the tasks demanding additional operations of classification thinking (logical comparison of two subordinate names, logical multiplication, limitation of the name volume), as well as knowledge of logic classes (Kurbanova, 2014).

2.2. Stages of study

A modified experimental procedure included 3 stages.

Stage 1. The participants individually did the comparison tasks as developed by the original method. According to the instruction, it was necessary to give multiple answers to each task and select the best one.

Stage 2. Participants of Stage 1 worked in random pairs. These pairs discussed the answers they had given at the previous stage, worked out the best common solution and proved its advantages. The material was presented by the combinations of logically correct decisions; improving decisions meant the reduction of the degree of similarities (differences). 3 types of tasks (comparison according to the degree of similarity, synthesis of independent features, and concretion) were done in pairs in different ways.

Stage 3. The subjects individually solved 3 types of tasks, which required the implementation of logic of classes. Each operation – logical comparison, logical multiplication, limitation of the name volume – acted as a means to improve the comparison advanced at stage 2.

Task 1. Comparison according to the degree of similarity. Two correct answers involved an act of inclusion (subordination); the improvement of comparison is the choice of the name with larger content and smaller volume (logical operation of comparing the subordinate names).

The question "How are a banana, a peach and a potato alike?" There were two correct answers: a) "everything is food", b) "everything is plant food". Which answer is the best? Explain your choice.

Task 2. Intersection of classes. Two correct answers are the names of independent classes; to improve the solution the overlapping of classes (logical multiplication) has to be introduced.

The question "How are a banana, a peach, a potato, meat, milk and water alike?" There were two correct answers: a) "they are eatable", b) "they are all products of nature". Give a new – a third – answer which would weave together the two previous ones. Which answer is the best? Explain your choice.

Task 3. Specification. The solution of the original task of comparison was overly generic and abstract ("poor abstraction"); improvement of solution lies in its concretization (logical operation including the limitation of the name volume).

1) The question "How are a banana and a peach alike?" The answer: "They are eatable". Make the answer better.

2) The question “How are a handbell and a horn alike?” The answer: “They both make sounds”. Make the answer better.

2.3 Description of the survey sample

The participants of the experiment were the students of Kazan University of 4th and 5th year. Everybody studied the logic of classes during the course in formal or mathematical logic.

2.4 Methods of data processing

At stage 1, for each comparison task we counted the number and proportion of solutions containing direct violation of the standards of comparison ("complexes") and logically correct, but overly generalized and abstract answers ("poor abstraction"). For each type of tasks at stage 2 and for each operation at stage 3, we calculated the proportion of responses in which the final decision was better than the original. At stages 2 and 3 we counted the share of explanations which involved the logic of classes. With the help of χ^2 Pearson's criterion we compared the proportions of complexes and poor abstractions in the total number of answers and solutions among answers evaluated as the best by the students. We also compared the success of the solutions of each type at stages 2 and 3, and the success of solving different problems with each other at the same stages.

3. Results

3.1 General characteristics of individual answers for tasks of comparison (Stage 1)

We obtained 6352 individual comparison results (3463, for subtest 1, and 2889, for subtest 2). 4088 solutions – 2044 for each subtest – were nominated as the best. "Complexes" were observed in 638 cases (18.4%) in subtest 1 and in 495 cases, in subtest 2 (17.1%). The "best" solutions included 238 complexes in subtest 1 (11,6%) and 228 (11.2%) in subtest 2. "Poor abstractions" were present in 457 of the "best" solutions (22.4%) in subtest 1, and in 305 (14,9%) solutions in subtest 2.

3.2 Stages 2 and 3: collective improvement of individual comparison results

The results of improving individual decisions at the second (joint) stage are presented in Table 1.

Table 1. Improving the comparison by joint solution of stage 2 tasks

Type of task	General quantity of tasks		Improvement as a result of discussin (%)		Absence of improvement or deterioration (%)	
	Subtest 1	Subtest 2	Subtest 1	Subtest 2	Subtest 1	Subtest 2
1. Comparison according to the degree of similarity	97	121	48	50	52	50
2. Synthesis of independent features	56	88	36	32	64	68
3. Concretion	353	163	14	22	86	78

The comparison of the success of joint solving tasks of different types according to χ^2 Pearson's criterion at stage 2 showed significant differences between all types of tasks. The highest level of differences in both subtests is inherent to type 3 tasks, with the success of its solution lower than types 1 and 2 when the significance level $p < 0.01$. Less significant are the differences in the success of solving problems of type 1 or 2: in subtest 1, the differences are at the level $p < 0.01$, while the discrepancies for the second subtest were not established.

Table 2 shows the differences in performance of classification logic operations in the context of solving classification tasks of all 3 types and as separate operations.

Table 2. Successful solutions of comparison improvement at Stage 2, and in individual students' performance of respective operations connected with the logic of classes at Stage 3, according to χ^2 Pearson's criterion

Type of task for improvement of comparison and corresponding operation of the logic of classes	Subtest 1			Subtest 2		
	Improvement of comparison (%)		Comparison of two stages Level of distinctions adequacy	Improvement of comparison (%)		Comparison of two stages Level of distinctions adequacy
	2 nd stage	3 rd stage		2 nd stage	3 rd stage	
1. Comparison according to the degree of similarity / logical comparison	48,4	96,1	$P < 0,001$	49,6	80,2	$p < 0,001$
2. Synthesis of independent features / logical multiplication	35,7	60,7	$P < 0,001$	31,2	76,6	$p < 0,001$

3. Concretion / limitation of name volume	14,3	46,9	P < 0,001	22,1	46,9	p < 0,001
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3.3. Ways to support the assessment of the solutions as the "best" at stages 2 and 3

The correlation of different types helping to explain the assessment of solutions as the "best" at stage 2 is shown in Table 3, and performing the respective operations at stage 3 is shown in Table 4.

Table 3. Reasons for evaluating the result of comparison as the "best" in joint solutions at stage 2

Forms of explanation	Subtest 1		Subtest 2	
	quantity	%	quantity	%
1. Explanations by the logic of classes: quantitative evaluation of similarities /differences	sum total 25, including	sum total 18,2%, including	sum total 22, including	sum total 17,3%, including
1.1. Comparison by the volume of classes	1	0.7	1	0.7
1.2. Comparison of name meanings by the quantity of characteristics	24	17.5	19	13.9
1.3. The simultaneous registration of the volume of class and name meanings	0	0	2	0
2. Explanations are not based on logical classes	112	81.8%	105	82.7%

Table 4. Reasons for evaluating the result of comparison as the "best" in individual operations of the logic of classes (Stage 2)

Forms of explanation	Subtest 1		Subtest 2	
	quantity	%	quantity	%
1. Explanations by the logic of classes: quantitative evaluation of similarities /differences	sum total 118, including	sum total 56,2%, including	sum total 121, including	sum total 33%, including
1.1. Comparison by the volume of classes	30	9.1	21	7
1.2. Comparison of name meanings by the quantity of characteristics	141	42.8	91	23
1.3. The simultaneous registration of the volume of class and name meanings	14	4,3	9	3
2. Explanations are not based on logical classes	141	43.8%	178	67%

4. Discussions

4.1. Description of individual solutions for problems of comparison at stage 1

The abundance of complexes among individual comparison results did not confirm the literature data on their disappearance in students' thought. Complexes were registered in more than 1/6 of all responses received. Among the solutions that were identified by every student as the best they were registered less frequently – in about one out of ten tasks in both subtests. We assumed that the responses-complexes in solutions are the result of students' carelessness and lack of motivation. The assumption that during the discussion in pairs the students will systematically identify complexes and eliminate them was not confirmed. At the end of the joint stage, the number of complexes in the joint solutions did not decrease – on the contrary, it increased. According to the analysis of protocols, the students found it difficult to explain what exactly in complexes did not correspond to normal comparison operations (Olver, 1995). A significant number of poor abstractions among the "best" individual responses also gave the opportunity for improvement at the first joint stage.

4.2. Discussion: the results of improvement of individual comparison results by the students at the second and third stages

The instruction at stage 2 was aimed at increasing the motivation of the students. The feature of the stimulus material in this method (the words of everyday language) pushed examinees towards solving these tasks as conventional. To initiate scientific thinking in students, the instruction emphasized academic and cognitive nature of the tasks. Discussion in pairs was presented to students as an opportunity to improve individual solutions.

To improve the results of comparison in the logic of classes means to reduce the measure of the commonness in formulating the similarities/differences. Only in the task of comparison according to the degree of similarity in subtest

2, half of joint responses were better than two previous individual ones (Table 1). In the other 5 tasks, joint responses were worse than individual. Most often comparison results were improved when the students compared more concrete and more abstract answers. Since in these tasks the similarity is more obvious, it encouraged students to discuss the solutions based on the logic of classes.

Two correct definitions of similarities/differences are equal within the logic of classes. When a pair of students discussed the relationship of individual solutions made at stage 1, in 36% of cases in subtest 1 and in 32% of cases in subtest 2 they combined two independent characteristics in a single response by performing a logical multiplication. A new joint response included both individual ones. Thus, within the logic of classes it came as the best out of 3.

Specification of overly generalized responses occurred less frequently; in 86% and 78% of cases in two subtests joint responses were not better or even worse than the original. While two answers with different levels of similarity in type 1 task push the students towards using the logic of classes, overly abstract answers do not.

In general, we can state that joint decision of all three types of tasks did not improve individual comparison results sufficiently.

This has prompted us to explore further the extent to which students can cope with operations of the logic of classes necessary for improving the results. As it is shown in the Table 2, the execution of separate operations (logical comparisons, logical multiplication, limitation of name volume) at stage 3 is higher than at stage 2. The differences between the results of stages 2 and 3 were significantly higher in all 6 tasks of both subtests. Thus, students have mastered the relevant operations, and perform them on the same stimulus material. However, these operations are rarely used as a means of comparison results. It correlates with already received ideas and outcomes: everyday, conventional thinking is a frequent alternative to the scientific, theoretical way even in educated adults (Vygotsky, 1962; Vinner, 2007).

4.3. Discussion of ways of supporting the assessment of the solutions as the "best" at stages 2 and 3

The ways in which students justified their answers as the best identify the positions they assumed to understand and analyze the tasks. In order to consciously use the necessary operations (logical comparisons, logical multiplication, and limitation of the name volume) for the improvement of initial solutions, the task must be identified as a problem in the relationship between classes. In this case, the criterion for evaluating the comparison is a measure of generality.

In the responses where a pair of students improved the original individual results, i.e. applied the necessary operations of the logic of classes, we registered how the students explained their decisions. As it can be seen from Table 3, in a joint discussion less than 1/5 pairs (18.2% in the tasks of subtest 1 and 17.3%, of subtest 2) based the evaluation of the best solution on the logic of classes. Almost in all these cases the answer was called the best because "it had more features, was more specific". Only one pair in both subtests referred to a smaller amount of the class; two pairs in the tasks of subtest 2 named both interrelated concepts – the content of the name and the volume of the class. The absolute majority of pairs who identified the best similarity/difference with the maximum content and the lowest amount (81,8% and 82.7% for two subtests) nevertheless explained this assessment using the considerations unrelated to the logic of classes.

After performing separate operations of logical comparison, logical multiplication, and limitation of the name volume, the proportion of examinees who explained the evaluation of the response quality within the logic of classes increased (Table 4). In the tasks from subtest 1, it rose higher – up to 56.2%, in subtest 2 – to 33%. As it also was in stage 2, students often referred to a greater number of characteristics (42,8% and 23% in two subtests). 30 examinees in subtest 1 and 21 in subtest 2 (9.1% and 7% respectively) indicated a smaller name volume. 14 students in subtest 1 and 9 in subtest 2 (4.3% and 3% respectively) specified both the volume of the class and the meaning of the name.

Thus, at stage 3 while executing logical comparisons, logical multiplication, and limitation of name volume as separate operations, the students performed them out more successfully and more often assessed the quality of the results in terms of the logic of classes. Such situations have highlighted their power of classification thinking at the theoretical level. In case where the requirement to perform the specified operation was not provided by the instructors, students rarely regarded the tasks as involving the logic of classes and solved the classification tasks on the base of conventional thinking.

5. Conclusions

The research conducted led us to the following conclusions:

- 1) Development of classification thinking in adults at the relevant scientific and theoretical level involves the systematic use of classification tasks which involve the notions and language of the logic of classes in the process of solving.
- 2) The integration of separate mental operations of the logic of classes as a part of classification thinking in adults assumes that the comparison operation is regarded as the inclusion of members into the comparison class (or additional classes), the quality of the comparison is viewed as a measure of its generality, the improvement of comparison – as a reduction of the measure of similarity, other operations of classification logic – as a change in measuring the similarity.
- 3) The developed method and the experimental procedure of the joint improvement of individual comparison results can be regarded as a means of studying classification thinking in adults as a scientific-theoretical one. It allows us to study

the ability to solve 3 types of problems: comparison of two subordinate class names, synthesis of two independent features of resemblance, and specification, including a reliance on logic classes.

4) We have found out that the use of operations of classification logic as a means of solving classification problems on the verbal material falls behind the level of students' mastery of the relevant operations, namely these of name limitation, logical multiplication, and comparison of subordinate classes.

5) The most successful joint improvement of comparison has been performed in the process of comparison according to the criterion of similarity; it has been used less effectively in the tasks of sign synthesis, and least successfully, in specification tasks. The same correlation of quality in the results has been observed in performing the respective operations of the logic of classes as isolated.

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