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The Role of the Image in Problem Solving

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THE ROLE OF THE IMAGE IN PROBLEM SOLVING

In recent years there has been a great upsurge of interest in the role of imagery in learning. At first blush this appears to be no more than a return to old arguments over the existence of images and the possibility of imageless thought.

As this article indicates, the old arguments no longer are of interest. Instead, a process of forming images is assumed and its role in problem solving is at issue.

The recency of references to the American literature testifies to the author's awareness of contemporary American events. Unfortunately, her cursory description of Soviet work will make replication or extension difficult. One clearly Soviet aspect of her report is the emphasis on teaching imagining as a pedagogical technique, an idea that bears further development.

Introduction

This article deals with visual images arising during the process of problem solving with given material (visual or textual), or from previously seen materials. We hold, as do many other psychologists, that the terms "image," "representation," and "mental picture" are synonyms and that an image is visual knowledge. (1)

In psychology abroad the problem of the image was for a long time given little attention; but in the last decade, as Holt (12)

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observes, interest in it has risen in various branches of psychology, though he does not include educational psychology among them. In educational psychology the problem of visualized ideas and their functions in the learning activity of schoolchildren is hardly being studied at all, if one judges by the numerous books titled "educational psychology," "the psychology of learning," etc.

In Soviet research, the problem of the image is studied in various fields of psychology: general, educational, engineering, etc. Nevertheless, inadequate attention is given to this problem.

A special feature of present-day studies of this problem is the fact that the image is regarded as an active phenomenon. Its regulatory role in human activity is studied, as are generalization of the image, its transformation, processing by thought, etc. (as is validly emphasized by M. S. Rogovin [8]). Treatment of the image in this fashion is particularly characteristic of Soviet psychology (the work of F. N. Shemyakin, A. A. Smirnov, I. M. Solov'yev, B. G. Anan'yev, E. I. Ignat'yev, O. I. Galkina, and others).

Let us note the principal features of the image that distinguish it from other mental phenomena. In a mental picture, objects have a definite spatial arrangement, and the picture may be "projected" (consciously or not) upon a given or imagined flat surface. The image may have a static or dynamic character (in the latter case, when the visualized object is mentally moved or changed). The characteristics of the image include its structure, which is defined by the relationship between the image and a word and its concept: In the first place, is the image unique or generalized, i.e., does it reflect significant attributes entering into the definition of the concept; in the second place, how precisely are significant attributes expressed in it? (2)

In the present article we take as point of departure the well-known proposition that in problem solving, major significance attaches to the transfer of previously mastered techniques, particularly learning techniques. (3) In certain cases transfer becomes active (for example, when the transfer of the technique of "mental visualization" involves the creation of a new image

every time, or when a new technique is found on the basis of one already mastered).

The following are the basic questions dealt with in this paper:

1. What are the distinguishing characteristics of generalized techniques for creating an image, and what is their place in problem solving (are they independent or part of a general technique)?

2. What are the characteristics of the image itself, its relation to the generalized technique, and the role of the image in problem solving?

To shed light on these questions, we examined the solution of learning problems in our investigations (Part 1 of the article) and also analyzed the solution of a number of problems in memorizing, verbal logical thought, etc., in the works of other psychologists, Soviet and foreign (Part 2 of the article).

1. The Image and Generalized Techniques in Solving Learning Problems

As they study certain learning problems, schoolchildren develop special techniques for creating images. For example, in a geography course, pupils master the technique of "imagining" a locality by means of a topographic "map" (see [4]). This technique consists of a number of operations. The pupil examines a topographic map in a definite sequence and imagines objects and elements of the locality in their spatial relationships. In imagining objects, he supplements them in his mind (inasmuch as a symbol of, say, farmland does not show details — what grows on it, etc.). The use of this technique in problem solving consists of creating a single image (reflecting the given locality), which is new in each problem. Thus the image presents itself here as the result of the solution of a problem. In the process of solving such problems, schoolchildren develop a generalized technique for creating images, which is revealed as it is transferred from one assignment to another.

A generalized technique for developing an image based on a drawing (projections) is formed analogously, a single new image being created in each assignment.

In such problems an image (for example, a spatial body based on projections) is created by various means, depending on the degree to which the technique has been mastered and on other conditions. It may be treated (a) by the so-called "trial and error" method; (b) gradually, as the pupil analyzes and compares three projections, and then creates an image based on them, step by step; and (c) "all at once" (by "insight"), as when the pupil immediately "sees" the spatial body in his mind. (4) The means whereby images are created also depend on the sequence in which the pupil examines the given visual material, the elements with which he begins to create the image, and what knowledge he employs (concepts and visualized ideas previously developed, and so forth).

If the pupil has not mastered a generalized technique for creating an image, either the result will be an image inadequate to the problem (not corresponding to the topographic map or drawing) or the pupil will lose the image in his attempt to "imagine" it, and this instability of the image will have a negative influence on the solution of the problem.

Let us adduce certain facts demonstrating the role of the synthesized image (along with the individual one) in the solution of learning problems. In one experiment, a pupil in the 6th grade mastered the theorem for the exterior angle of a triangle by means of a (textbook) drawing and the technique for drawing up a plan for proving this theorem. As he erected further constructs on the drawing he differentiated between their significant aspects expressing the plan of proof, i.e., its fundamental components, and an insignificant one (from the standpoint of the plan). (5) In a task involving transfer, the pupil is asked to construct, on a new version of the drawing, a plan of proof of the same theorem, to carry out supplemental construction, and to describe the plan of this construction.

In transferring the technique, the pupil performs a number of operations, in which he makes use of two images. First, he recalls the plan of proof with the help of the image: the pupil conceives the first drawing in memory, mentally separating in it the significant and nonsignificant aspects of the additional

constructions. This reworking of the first image gives it a special structure: it becomes a generalized bearer of the technique of compilation of a plan of proof of the theorem. (6) Second, the pupil creates a new image: he mentally takes into account the significant aspect of the constructs added to the first image (the median moves in the direction of the exterior angle) and then, on the basis of this image, mentally (in imagination) completes the assigned drawing — performs additional constructions on it in his mind (for example, drops the median, while in the imagined first drawing it was carried to the right). As a consequence, the pupil "sees" the assigned drawing of the triangle in his mind, with all the additional constructs. This is the second image, which is the result of a spatial solution of the problem on the basis of knowledge of the plan of proof. On the basis of this second image, the pupil "reckons" the added constructions from it, performs them in actuality on the assigned drawing, and can describe the plan of proof of the theorem. (7)

Thus, in this case, "imagining" the drawing by memory and creating the second image become part of the major technique (of drawing up a plan for the proof of a theorem). The first image is a generalized "carrier" of the compilation technique and plays a dual role in solving the problem. It helps one to remember the technique and serves as a base from which to proceed to the next stage of solution of the problem. A new second image is created each time (on the basis of new variants of the drawing). However, as this occurs the means by which it is created becomes generalized and is carried over to subsequent problems. Its role in solving the assigned problem is expressed in the fact that it serves as a base for actually carrying out additional constructions.

If the technique for compiling the plan of proofs is wrongly shaped, schoolchildren develop an initial image that is not adequate (in which the significant and nonsignificant aspects of the additional constructs are not separated). This image exercises a negative influence on the solution of the problem. The pupil does not succeed in creating an adequate second image,

and he attempts on the new drawing mentally (and actually) to carry out precisely the same supplementary constructions as on the first drawing (he carries the median to the right, and so forth). We have previously described this form of negative influence of visual material and called it "constraint by a special case." (8)

Let us present an example of a somewhat different relationship between image and generalized technique. A 5th-grade pupil had mastered the technique for determining the cardinal points of the compass on the spot by facing north, pointing to the right, which is the east, and so forth. On a sheet of paper he drew a diagram in which the cardinal points were depicted by four arrows directed outward from the point at which he was standing. The pupil had also assimilated the fact that in solving the problem it is necessary to distinguish between two systems of directions: a fixed one for the given point (N-S-W-E) and a dynamic one (in front — behind — to the left — to the right), depending on the direction in which the observer is facing. (9) In technique transfer problems, it is proposed to the pupil that he identify the compass points when he is facing east, west, and south (when north is in a known direction). In solving this problem, the pupil carries out a number of operations constituting the technique:

1. He imagines the set of directions (as depicted on paper) and relates them to the given locality.

2. He modifies the diagram mentally by adding to it one more (a fifth) arrow, leading from that denoting north, and in his mind bends it in an arc around the point at which he is standing. The length of the bent arrow depends upon the task. If the pupil is facing east, he extends it to the arrow denoting the easterly direction, and so forth. This reorganization of the image shows that he has distinguished in it the two systems of directions (while the bent arrow of changeable length expresses the dynamic system of directions). On the basis of this image, the pupil demonstrates the directions at the given place when standing facing in different directions.

If the pupil had not properly mastered the technique for de-

termining directions and had not distinguished the two systems of directions in the visualized diagram, the image would have a negative influence on the solution of the problems. Sometimes this is expressed in "constraint" by the diagram of directions depicted on paper (for example, a pupil shows the northerly direction as having to coincide with the direction "forward" no matter what the direction in which the observer is facing).

Thus, the method of "conceiving" the diagram of the cardinal points and its reorganization becomes part of the larger technique (of determining directions). At the same time, this mode becomes a generalized one. The image (the conceived diagram, supplemented by a fifth arrow) is also generalized, becoming a "carrier" of the technique of determining directions. The role of this image lies in the fact that it serves as the basis for differentiating between the two systems of directions and also for demonstrating directions in new tasks. (However, this image is not the result of spatial solution of the problem.)

A special relationship between image and generalized technique is revealed in an analysis of certain facts in a study (performed under our guidance) by D. K. Gilev (3). He developed, in 5th graders, visualized ideas of standard distances (50 and 100 meters). Then they developed a technique for measuring distances by eye. Upon transferring this technique to new tasks, the pupils performed a number of operations constituting the technique: (1) they conceived the required standard, say, 50 meters, from memory; (2) they created a second image as follows: the imagined standard was superimposed mentally upon the distance offered, and they mentally "saw" the given distance separated into several 50-meter segments (this image was the result of spatial problem solving); (3) they mentally "counted," using the second image, how many times the standard was contained in the given distance and calculated the latter accordingly.

Consequently, the "visualization" of the standard (the first image) and the creation of the second image (by means of imagination) fall within the technique of visual evaluation of distances. The first image serves as the material for building the second image, which is new in each new task, i.e., is unique in

character. But the means of creating the second image ("superimposing" the standard upon the given distance) is generalized and transfers to subsequent tasks. The second image, being a spatial solution of the task, serves as basis for verbal-logical solution.

It should be remarked that the generalized nature of devices for creating images was, in all the cases cited, relatively narrow, inasmuch as the transfer was tested using problems analogous in type to the learned one.

As has been shown in a number of investigations, the development of broadly generalized techniques (including image-creation techniques) is a most important condition for the mental development of schoolchildren. This is achieved by the implementation of three stages in the development of techniques: the introduction of techniques into various school subjects; teaching schoolchildren methods of transfer techniques; and leading schoolchildren to generalization of analogous devices from one subject to another and to systematization of various devices. It is also necessary to class with the conditions of mental development the presence of knowledge, particularly visualizations developed in schoolchildren (inasmuch as visualizations pertain to knowledge and the latter, as we know, is an important condition for development).

Among the indices of mental development, the enlargement (with age) of the range of transfer of techniques, including techniques for creating visualizations, has special significance. From the standpoint of interaction between learning and development, we examine the transfer of generalized techniques as a link completing the "bridge" between learning and development (for it is precisely in this link that the influence of learning upon development is realized [4]). We ascribe special significance to the problem of interaction (viewed from the standpoint of age) between two lines of development — mental development expressed in particular indices, and age-governed changes in the phenomena we relate to the conditions of development (concepts, visualizations, assimilated techniques, including the techniques of creating visualizations) (5).

2. Image and Generalized Techniques in Solving Problems in Memorizing, Logical Thought, etc.

The important role of the image in problem solving and the role of transfer to new problems of generalized techniques for creating images emerges in the solution not only of learning problems but of problems in memorizing, logical thinking, etc. This is confirmed by analysis of a number of works of other investigators.

In psychology abroad, wide use is made of problems in which "visualization" becomes a generalized technique and is transferred to a new task (in which new images are employed each time.) Thus, for example, Paivio (14) treats images (along with "verbal symbols") as "mediating links" or "codes" in memorizing word pairs. The positive role of the image depends upon a set of conditions (the features of the words, the character of the visualized idea, stimuli, individual differences, etc.).

In the research of A. A. Smirnov (9) and his colleagues (A. S. Novomeiskii, K. P. Mal'tseva, and others), the role of the image in memorizing is studied on a broader plane. The creation of an image (on the basis of a text) is studied as a component part of image memorizing, while the role of the image is associated with its structure. For example, the generalized image — "carrier" of the meaning of the text — is the "base point" of memorizing and reproduction of that text. The role of the image is demonstrated in combined content, in reconstruction of the text when it is reproduced, in drawing up a plan in accordance with the text, etc.

In Huttenlocher's work (13), the subjects, called upon to solve a syllogism, created spatial images by the following technique. The terms of the first premise would be placed by the subject in, say, the upper corner of the imagined plane, to which a third term was then added, the construction proceeding downward or to the right (i.e., as in reading). The terms of the premise were expressed in the form of complete words or abbreviated denotations. This image, new each time (in new tasks), was the result of spatial problem solving.

With respect to these facts the following question also arises: If the subjects solve a series of analogous questions, is it possible that a generalized technique for creating an image is formed (although the image is a new one each time) and that this technique becomes incorporated into a larger technique for identifying relations among terms of a syllogism? If such a technique actually forms, it must be expressed in the transfer. Here the role of the image consists in being a base for solution of the syllogism.

In work by Frandsen & Holder (11), an attempt was made to teach subjects a "visualization technique" (10) for creating spatial images in solving verbal problems (based on syllogisms).

B. F. Lomov (6) has shown that the construction of a drawing may take the form of a method of graphic solution of physical problems. The author emphasizes that mastery of this method includes generalized knowledge about it and a base image (which is generalized and expresses not only the drawing but the sequence by which it is constructed). If the base image is shaped by means other than generalization, this will be revealed in "constraint by a special case." Thus, for example, a pupil masters addition of velocities by means of an example in which the velocities are angular and the resulting motion is expressed by a diagonal of a parallelogram (moving from its lower left-hand corner to its upper right-hand corner). A new task then requires finding the resultant motion of a parachutist (when rate of fall and wind velocity are known). The pupil, seeking to transfer the mastered technique to this task, employs the drawing familiar to him and constructs a new one so that the parachutist seemingly flies upward.

I. S. Yakimanskaya (10) has studied the role of spatial visualizations in solving technological problems (in making parts on a turning lathe). She demonstrated that pupils utilized their experience in reading drawings to read a flow chart. This chart included a drawing of the rough blank, one of the finished part, and "sketches of transfers" (in which changes in the shape and dimensions of the blank resulting from particular operations are shown). The image of the finished part and that of the

changing blank served as regulators guiding the work on the lathe.

It would seem that the positive role of images in these cases was determined by the fact that the pupils had mastered the technique of "visualization" and had transferred it to reading the drawings and sketches on the flow chart.

In a study by M. E. Botzmanova (2), a technique of graphic analysis of a problem in arithmetic has been developed. It would seem that this technique includes, as a regular component, creation by the pupil of a spatial image (expressing the relationship among the given conditions). This image is the result of spatial solution of the task. The pupil creates a new image each time, but the method by which this occurs becomes generalized — once the technique of graphic analysis is mastered. The role of this image apparently consists in the pupil's "counting" from it, sketching a model that he uses in solving the problem.

D. B. Bogoyavlenskaya (1), in one series of her investigation, demonstrated that, in solving an arithmetic problem, the subjects developed a spatial image (in the form of a straight line divided into segments, spirals, a number of arcs, and the like). She interprets this image from the standpoint of V. N. Pushkin's postulates of the image-as-model (as a "vision" of the task, an understanding of its conditions), which guides the search for a solution, etc.

It is possible that in this case as well, there may appear in the subjects, under certain conditions, a generalized technique for creating an image (a new one each time) that is the result of spatial solution of the task. This determines the positive role of the image.

In a laboratory experiment, D. A. Oshanin & L. R. Shvebek (7) offered systems of points (on small maps) to the subject to memorize, these points being concealed by broken lines. The subjects worked over these systems mentally, disregarded the broken lines, and joined the points all over again, for example, by drawing horizontal lines mentally. Then the subjects used this new image as a basis for reproducing the system of points by pressing a button on a panel. (11)

In some cases, the subjects did not rework the system of points in memory and, in reproducing it, sought unsuccessfully to visualize it in the form in which it had been shown them. This image had a negative effect upon the solution of the problem.

In our view, the creation of the image (mental processing and reproducing of the system of points) in this case may be regarded as a generalized technique transferred to new assignments. This technique is capable of assuring the building of a new image each time and of providing a positive role for the latter in problem solving (when the subject "counts" the system of points from this image in reproducing it). The negative role of the image would seem to be determined by the fact that subjects did not master a generalized technique for creating the image.

Conclusions

1. Analysis of the experimental material in our investigations, as well as in the works of other psychologists, demonstrated that images in problem solving come to play a positive role if the following conditions are present: (a) the subjects transfer generalized means of creating an image (from one task to another); and (b) these generalized methods appear in some tasks as the fundamental techniques for solving them and in others as a component of more inclusive techniques.

The negative role that images can play in problem solving points to the fact that subjects have not mastered generalized methods of forming an image.

2. Depending on their structure and the means for creating them, images exercise different positive influences upon problem solving: (a) the support function of a generalized image may express itself in the fact that it guides the solution of the task and that the subject takes off from it (when the image is the "carrier" of the meaning of the text — in the psychology of memory; when the image has been processed by a factoring abstraction and is the "carrier" of the generalized technique of

learning, for example, development of a plan for proving a theorem, and so forth); (b) the support function of a unique image (new in each task) lies in the fact that it is the result of a spatial solution and that the result is "reckoned" from it (it may be assumed that in these cases the subjects make use of a generalized system for creating an image); and (c) in some cases the image plays an "auxiliary" role: when it serves as material for building a second image or as a mediating link in memorizing words.

3. Generalized techniques for building images play an important role, among the conditions of their development, in the mental development of pupils, and broadening the sphere into which they are transferred is an important index of pupils' development.

Notes

1) In contemporary Soviet psychology, the psychological term "image" is sometimes wrongly confused with the epistemological meaning of this term in Lenin's theory of reflection (in which sensation, perception, conception, thought, notion, etc., are synthesized under the term "images of the world without").

2) For a survey of the literature on the structure and functions of the image in thinking, see reference 5.

3) The techniques of learning are the means by which a pupil learns and solves learning problems. A technique consists of definite acts, which may be expressed objectively by listing them (rules, instructions, precepts, etc.). For detail on techniques and transferring them, see our book (reference 5).

4) These three methods pertain to any of the images to be discussed below. These same methods (trial and error; gradual approach; insight) have been described repeatedly in psychology as different approaches to problem solving, depending upon the difficulty of the problem, the experience of the subjects, individual differences among them, etc.

5) The plan of proof in additional constructions includes the principle of construction, for example, the fact that the median

is carried in the direction of the exterior angle regardless of its location, and the like; the nonsignificant aspect is expressed, for example, in the fact that in the given drawing, the median is carried to the right (which depends on the location of the exterior angle).

6) This image bears a similarity to the image ("carrier" of a notion), in which the significant and nonsignificant attributes of a notion are differentiated (for example, with respect to the exterior angle of a triangle).

7) This phenomenon of "counting" a solution of a problem from an image has been described repeatedly both in the foreign and the Soviet literature (including writings by the present author).

8) This phenomenon was subsequently confirmed in many pieces of research (Soviet and foreign) and was denoted by a variety of terms: "constraint by a drawing in a book," "confinement of thought to the drawing in a textbook," "habituation to stereotypes," "constraint by a standardized drawing," etc.

9) These two systems of directions are differentiated in the writings of F. N. Shemyakin, B. G. Anan'ev, and others.

10) In our terminology, "the technique of visualization" is the method by which an image is created (or the means of "visualization").

11) The authors interpret this image as a usable one: it is adequate to the task and expresses the adequate structure of the object, making possible a correct solution of the problem.

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