

Demidov Yaroslavl State University

*As a manuscript*

Sergei Yurievich KOROVKIN

**MENTAL SCHEMES IN INSIGHT PROBLEM SOLVING**

Specialty 19.00.01 – General psychology, psychology of personality,  
history of psychology

Dissertation summary  
for the purpose of obtaining academic degree  
Doctor of psychological science

Yaroslavl – 2020

The relevance of the research topic lies in the fact that, following the rapid growth of data in cognitive psychology, disputes between several theories of human thinking have become more acute. Current research is based on one of two opposing approaches to the explanation of insight solutions: the problem space theory and the representational change theory. The divergence of the conceptual apparatus of the proponents of the approaches leads to a narrowing of the angle of scope of each of them and the loss of points of contact. This conceptual divergence significantly impoverishes the field of insight problem solving psychology. In our opinion, these divergent views on the nature of insight have many intersections. This work is aimed at constructing a framework that would allow filling theoretical gaps that remain outside the interests of both theories.

The fundamental theory in cognitive psychology that describes the process of problem solving is the problem space theory (Newell, Simon, 1972). According to this theory, the process of problem solving is a transition from an initial state to a goal state using various mental operators and heuristics. This theory successfully describes and simulates algorithmic-type thought processes by using artificial intelligence algorithms. So-called “insightful” problems can also be described via rational principles by the progress monitoring theory (McGregor, Ormerod and Chronicle, 2001). According to this theory, the process of problem solving is based on the maximization heuristic and the progress monitoring within a mental look-ahead. It takes into account the meta-cognitive component of the solution – monitoring of approaching a goal. However, this theory successfully describes the problems with a well-defined goal state. But there is a large class of insightful problems with ill-defined goal states, for which the existing heuristic models are ineffective. The development of artificial intelligence models is going in the same direction, with lack of attention to the so-called “creative” or “intuitive” processes. As a rule, sequential and algorithmic solution processes are simulated but intuitive decisions that can be modeled as signals between parallel cognitive systems are overlooked.

An attempt to include the creative component of the solution in the cognitive theories is carried out within the framework of the neo-gestalt-psychological theory of representational change developed by Ohlsson (1992, 2011). In this theory, the creative component that has been taken out of the brackets of the problem space theory is the process of changing an inefficient representation. From this point of view, the theory of Newell and Simon describes only movement within the problem space constructed on the basis of an initially formed representation. If a problem cannot be solved within the initial problem space, a solver gets into an impasse. The way to overcome this impasse is to change the representation and, as a result, to form a new problem space. In this case, the creative process in problem solving is the process of representational changing. However, today there is no unity in understanding what cognitive mechanisms make such a change possible.

In addition, at present, a large number of descriptions of various phenomena of insightful solution have been accumulated: aha-experience, changes in psycho-physiological indicators during insightful solution, the absence of a sense of approaching the goal, and many others. However, there is no single theory of the insight process that would solve diverse theoretical problems related to the explanation of insight, and would satisfy all researchers. To develop such a model, it is necessary to take into account not only cognitive processes, such as perceptual reorganization, load of working memory, movements in a problem space, etc., but also the high-level components of the insight solution. The study of this layer of data and their inclusion in the context of cognitive theories of insight solutions, as it seems to us, will not only allow us to explain such phenomena as confidence in an answer, non-random preference for one of the equally probable alternatives to the solution, solver's awareness of an impasse, emotional experiences in the process of solving, but also will shed light on the cognitive processes themselves involved in the process of insight solutions. In addition, such a theory could overcome the problem of disparity of data and aspects of research in the field of insight problem solving.

**The aim of the study** is to identify and describe the mechanisms of representational change in insight problem solving.

**The main purposes:**

1. To analyze the main trajectories of theoretical development in psychology of insight problem solving.
2. To identify the main advantages and disadvantages of the key theoretical approaches to explaining insight as a change in representation in solving the problem.
3. To propose a framework of mechanisms representational change in insight problem solving that compensates the shortcomings of the mainstream theories.
4. To demonstrate that the restructuring of representation in insight is based on scheme modification mechanisms.
5. To identify relationship between insightful solutions based on the modification of schemes and subjective aha-experiences.
6. To identify the role of the processes of building a new representation in during problem solving after abandoning an old representation.
7. To identify the role of working memory in the process of constructing and changing the representation of a problem.
8. To analyze the possibilities of using of high-level analysis of contradictions between schemes for solving insight problems.

**The hypotheses of the study:**

In this work, the mental schemes in insight problem solving framework has been developed, for experimental verification and proof of which a number of hypothetical assumptions must be verified.

1. The representational change in insight problem solving is available for high-level processing, which is manifested in the activity of working memory executive processes at the stage of the representational change. Confirmation of the first hypothesis will demonstrate the availability of the insight solution for high-level processing.

2. The availability of high-level processing of representational change in insight is possible due to the presence of explicable structures during solution that can be used to change the representation. Confirmation of the second hypothesis will demonstrate the presence of high-level cognitive structures that a solver can manipulate to change the representation.

3. Finding and discovering mental schemes is an effective way to solve insight problems. The discovery of a mental schemes during solution of an insight problem is the basis for the instantaneity of the insight solution. Confirmation of the third hypothesis is aimed at demonstrating the connection of the phenomenon of insight solution with the use of schemes in problem solving.

**The methodological basis of the research** is the principles of the information processing approach to problem solving and insight phenomenon (Simon, Newell, Kaplan, MacGregor, Chronicle, Ormerod); the provisions of the representational change theory (Ohlsson, Knoblich, Öllinger, Danek), the principles of the theory of cognitive schemes (Bartlett, Neisser, Piaget, etc.); the functional principle aimed at identifying the dynamics of changes in mental processes during problem solving (Duncker, Metcalfe, Ponomarev, Spiridonov, Tikhomirov, Öllinger, etc.).

To achieve the aim and purposes, as well as to test hypotheses the following **methods and techniques** were used. The main scientific method used in this work is the experiment. In a series of studies, all the necessary requirements for conducting a psychological experiment were met such as a strict control of variables, stimuli randomization, use of objective and measurable indicators as a dependent variable, etc. The variety of experimental effects was provided by various methods and methodological techniques, some of which were developed specially for this work. In the most general form, the experiments in this work were performed on the basis of the method of problem solving, that is, all the obtained effects were measured in a situation where intellectual, primarily insight, problems were presented as a stimulus material, and the characteristics of the solution process were measured

under various experimental conditions. Also, a long-term experiment was used in the work, which was aimed at studying the formation of strategies as a result of solving a series of insight problems. However, as a rule, short sets of tasks were used in the studies. The method of hints was used to influence the solving process. Registration of the processes accompanying the insight solution was carried out using cognitive monitoring of working memory load, registration of motor movements, and the thinking aloud method. The subjective characteristics of the experiences accompanying the insight solution were measured using the survey method.

Data analysis was performed using various types of variance analysis with post hoc comparisons using the *t*-test with corrections for multiple comparisons. Data analysis of the frequencies of solution types was performed using the  $\chi^2$  method, the Yates-corrected  $\chi^2$  method, and the Fisher's exact test.

**The main provisions of the dissertation submitted for defense:**

1. Based on the theoretical analysis of explanatory models of the mechanisms of insight problem solving, it was revealed that the key criterion for the operationalization of insight solution is a change in the inefficient initial representation. Two opposite views on the explanation of how the change of representation is carried out are revealed: 1) from the point of view of the problem space theory, an insight solution is a high-level search in the space of all possible representations via non-specific heuristics, 2) from the point of view of the representational change theory, a new representation is formed due to low-level processes by suppressing an old and automatically assembling a new representation.

2. The mental schemes theoretical framework is formulated, which describes relationship between high-level and low-level processes in an insight solution. It analyzes the structure of the problem representation, the functions of schemes in the problem representation, and ways to change the problem presentation as mechanisms of insight solution. In accordance with it, a change in representation can occur both in a low-level way as a result of the ascending influences of spontane-

ously actualized schemes, and in a high-level way through a conscious search for a suitable scheme.

3. High-level processes, such as executive functions that are required to build a representation consistent with the goal, are involved in insight problem solving during the process of representational change. A purposeful construction and change of the problem representation are carried out in working memory. An intentional representational change can be carried out by conscious searching for a suitable scheme as a problem model or one of its components.

4. There are mental structures that can be learned from the experience of solving problems and transferred from solving one insight problem to another, such as procedural schemes and high-level heuristics. There is a possibility to solve insight problems via analysis of content and structure of a problem.

5. The representational change can occur either due to low-level processes of weakening of automated schemes, or due to high-level search of schemes in the form of analogy. However, since both ways of solving problems are difficult in insight problems, a third specific way of solving the insight problem is possible – solution via analysis of contradictions between schemes.

6. Restructuring of representation in an insight solution is based on scheme modification mechanisms. Detecting and modifying schemes can be an effective way to solve insight problems along with simple heuristic search.

7. The experience of elegance and insightful aha-experience can be the result of successful schematization due to which the solution or an essential part of the solution become available in working memory.

**The scientific novelty** of the work is determined by a number of theoretical, experimental and methodological innovations that will allow to describe and explain the mechanisms of representation change in insight problem solving. Methodologically, methods for analyzing the dynamics of working memory loading, a modification of classical insight problems, in particular, the modified 9 dot problem, are developed within the framework of this work. Experimentally, new exper-

iments are implemented that are both critical experiments for already existing theoretical ideas (about the role of low-level and high-level processes in finding a solution), and ways to test the ideas developed in this work (about the role of schemes in finding and detecting insight solutions). A long-term experiment was conducted to identify the possibility of learning when solving a long series of insight problems. Theoretically, the framework of mental schemes is proposed that resolves a number of theoretical contradictions between proponents of the information-processing approach, proponents of neo-gestalt approach and researchers of aha experiences in insight problem solving.

**The theoretical significance** of the study of mental schemes in insight solution is due to the fact that the concept of mental schemes in the insight research context allows to resolve a number of fundamental contradictions between the key theories of search and change of representation, and also allows to create a general theoretical framework for the analysis of insight-like phenomena such as aha-experience. This work is aimed to remove the contradictions between the problem space theory in which insight is a result of an analytical high-level search for a solution in a space of all possible representations, and the representational change theory in which the spontaneous insight is low-level automatic process of restructuring and assembly of a representation. The framework of mental schemes allows to take into account both the work of low-level processes of representation restructuring and high-level search for available solutions.

The mental schemes framework proposed in this thesis allows us to offer a rationale for combining disparate data on insight-like phenomena such as aha-experience. Aha-experience, from the point of view of this framework, can be not only a reaction to overcoming an impasse or changing a representation, but to the characteristics of schematization of a found representation.

The theoretical framework of mental schemes allows to overcome such theoretical difficulties and issues as: is it possible to learn how to solve insight problems, how possible targeted search for a solution being in an impasse, how high-

level and low-level processes interact in insight, etc. Solution to these problems opens up new perspectives in the study of insight to move this research area towards the successful modeling of the studied process.

**The practical significance** of the study is that the obtained results can be a basis for development of recommendations for teaching tools and methods of effective problem solving, as well as for recommendations for new algorithms for heuristic systems of artificial intelligence.

**The experiments** were conducted in the period from 2010 to 2019. During this time, a theoretical and methodological analysis of the problem was carried out, research procedures were determined, and the data obtained were collected, processed, and interpreted. The total sample size was 234 people aged 12 to 78 years. The sample size is sufficient in terms of the power of the study and the detected effect sizes.

### **The most significant results of the study:**

1. As a result of a theoretical analysis of insight mechanisms (Chapter 1), two approaches were identified, whose views on the nature of insight are radically different. From the point of view of a non-specific approach, insight is a kind of epiphenomenon, and the processes underlying it do not differ in principle from those through which the search for solutions in well-defined problems is carried out. The specific approach, on the contrary, states that there should be additional special mechanisms that allow making a breakthrough in the solution. According to the information-processing approach to thinking (Chapter 2), the cognitive mechanism of insight is a change of incorrect representation. The analysis of existing theories reveals two main views on the explanation of how the representational change is carried out. The problem space theory suggests that an insight solution is a high-level search in the space of all possible representations using non-specific heuristics for finding a solution. The representational change theory (Chapter 3) suggests that a new representation is formed by suppressing an old and automatically assembling a new representation. The positions on which the problem space

theory and representational change theory stand are usually considered as radically opposite in the form of specific and non-specific approaches. Therefore, a theory that reconciles the two radical points of view is required.

2. The solution to the problem of high-level and low-level processes in insight is the introduction of the concept of a mental scheme (Chapter 4). The scheme is understood as a cognitive structure that allows solver to simplify the representation in such a way that it is possible to operate with large parts of the representation within working memory. We refer to schemes that are determined by the conditions of the problem as a mental scheme. The mental schemes are available for conscious operation.

In general, the change of representation in an insight solution can be described as follows. The problem representation consists of parts that represent perceptual, motor, or mental schemes. The mental schemes are organized hierarchically. The problem representation as the set of all representations for the current problem at the highest level is encoded by schemes of a situational model of the problem, expectations, objectives and program of action. The underlying layer consists of elements, objectives, actions and sub-goals. Since the problem representation is a hierarchy of schemes, the representational change can occur as a result of a scheme change at any of the levels. Given the instability of the mental scheme, it can be changed as a result of the bottom-up influences of a spontaneously actualized perceptual or motor schemes, as suggested by the representational change theory. The availability of mental schemas to consciousness allows a conscious search for a suitable scheme for a situational model of the problem or one of its components, as predicted by the problem space theory.

If a suitable mental scheme is not available for conscious search in long-term memory and the situational model of the problem is stable, the analysis of contradictions between schemes within the representation of the problem could be the method of searching for a new representation. Such an analysis can be carried out at any level of representation, and its main purpose is to remove the representa-

tion of the problem from a stable equilibrium state. The latter type of representational change is not taken into account in the cited models and can be considered as a new prediction of the proposed theoretical framework.

3. The executive functions can influence insight problem solving. This is manifested in an increase in the load of executive functions in insight problems compared to tasks for the production of hypotheses. The executive functions provide the process of representational change. Insight problems are more demanding to the executive functions than creative tasks that do not require a change in representation. The obtained data on the load of executive functions indicate that it is impossible to explain the final stages of insight problem solving only due processes of activation of semantic networks (Chapter 5).

4. Explicable structures induct that form the basis of the experience of solving problems. Such explicable structures provide the possibility of transferring, that is, using previously obtained experience to solve new insight problems. Induction mechanisms of mental schemes play an important role in the transfer in insight problem solving via encoding a structure of the problem (problem situation) or a search for a solution. Based on the data of solving a long series of insight problems, the effect of learning to solve insight problems is revealed that is connected to development of schemes of a solution procedure (Chapter 6).

5. The high-level scheme processes in insight problem solving, in particular, is the analysis of consistency and inconsistency between actual schemes and their elements. The high-level processes in the form of analysis of contradictions between schemes in the representation increase the effectiveness of insight problem solving. An experiment showed that stimulating participants to use high-level processes aimed at analyzing contradictions between schemes in the problem representation leads to an increase in the effectiveness of solving the Katona's five squares problem. Strategies for solving insight problems as explicated structures in solving the problem can be based on operating with a content-nonspecific knowledge about the problem (Chapter 7).

6. The insightful solution can be a result of search and discovery of the final solution scheme, even if a step-by-step heuristic solution is available. The search for schemes in memory can be thought of as a purposeful search for a representation of the goal state, as opposed to a “blind” search for a sequence of actions. The scheme of the final solution provides a purposeful search due to the fact that it represents the image of the final goal state. The efficiency of using the final solution scheme is related to the ease of its recognition and retention in memory. The process of operating with mental schemes in solving problems is of a high-level nature (Chapter 8).

7. The aha-experience of an insightful solution is a consequence of schematization of the solution, the compact packaging of a solution into a scheme. A more schematized solution is evaluated as more insightful. This is manifested in the cognitive measurements of aha-experience (Chapter 9).

19.01.2021

 (S.Y. Korotkin)