**Poddiakov, A. Reshenie kompleksnykh problem v PISA-2012 i PISA-2015: vzaimodeistvie so slozhnoi real'nost'yu [Complex Problem Solving at PISA 2012 and PISA 2015: Interaction with Complex Reality]. *Obrazovatel'naya Politika, 2012, 6,* 34-53. (translated from Russian).**

*Abstract*

In 2012 the Programme for International Student Assessment (PISA), for the first time in the history of large-scale assessments, included a new type of problems called “interactive problems”. This article will analyze the problems. The research area behind it is the psychology of complex problem solving in a complex multi-factor environment which involves search, experimenting and control in conditions of uncertainty. The article discusses the new opportunities that open up and the problems that arise in introducing such problems in large-scale assessment practice, with particular focus on the problem of standard assessment of creative problems. It looks at the growing importance of studies into exploratory behavior and “experimentation with experimentation” and their impact on education policy.

In 2012 the participants in the Programme for International Student Assessment (PISA) were, for the first time in the history of large-scale testing and assessments, were offered a new type of problem, i.e. interactive problems with multi-factor objects. Russian sources devoted to PISA 2012 usually confine themselves to the bare statement that these are computerized problems (requiring interaction with a computer). It should be stressed from the start that computerization is by no means their main characteristic. They can well be implemented in a different shape, though the computer is at present the most convenient instrument for presenting their content (as well as registering the process of solution and the treatment of the results).

The key feature of these problems is that they require the student *to explore a new complex multi-factor system with properties not known in advance.* The student conducts the exploratory work not in a purely abstract-analytical way but by directly interacting with a new object, putting forward hypotheses and immediately testing them experimentally and trying to control the object. Those who developed PISA 2012 contrast these interactive problems with a different type of problem that they call analytical. In analytical problems all the information required for the solution is set in the conditions from the start (the absolute majority of school mathematical problems, intelligence test assignments, etc. belong to that category). This type of problems has its merits (otherwise it would not be used), but it completely omits the stage of gathering factual data, without which real cognitive activity is impossible. The participant is given the terms of the problem which he can work with on paper or in his mind, but he cannot obtain any new information from the actual object that is in the problem. All this information has been obtained or invented by the compiler of the assignment and is presented to the student ready-made. In interactive problems the search and acquisition of new information from the environment is the key part[[1]](#footnote-1) (Frensch, Funke, 1995). The problem of choosing and setting up an observation scheme, a plan for the experiment, etc. is fundamental for the process and for the results of the solution.

The Programme for International Student Assessment is one of the most ambitious modern projects being implemented by the Organization for Economic Cooperation and Development. It involves tens and hundreds of thousands of 15-year-old school students (about 200,000 in 2012) from dozens of countries and is aimed at assessing the competences, knowledge, and skills that are needed in real life, in practical activities. The assignments for it are constructed and selected by an international team of experts. This article will try to prove that the introduction of interactive multi-factor problems in such a large-scale project as PISA reflects some logical trends in changing the content of education and assessing educational achievement. The following questions will form the focus of this article.

What is the scientific basis for the construction of these problems? Let us say from the start that this is an extremely interesting area of modern cognitive psychology, the psychology of complex problem-solving which has been a big growth point in the last 30 years and is part of complexity sciences.

Why have these problems been introduced in PISA and what do they diagnose and how?

What are the complex problems this area of study throws up in introducing it in large-scale assessment practice? The solution of what problems includes this trend as its component part?

**Psychology of complex problem solving as a scientific area**

By complex problem is meant a problem that comprises many disparate sub-problems (sub-tasks) that are interconnected both directly and remotely, so that it is impossible to solve any of the sub-problems in isolation, separately, and one has to unravel everything simultaneously, often working against a deadline. The confusion and the multiplicity of links is part of complex reality. D.Dörner writes (1997, p. 106) that in a complex system there is an intertwining of dependencies that has the pattern of a mattress on springs: if you pull in one place everything starts to move, if you press at another point the same happens. So, while apparently doing one thing the problem-solver in reality acts upon a multitude of interconnected objects. As a result he may face side effects or remote consequences some of which are directly opposite to his goals. There are examples galore of activities involving the solution of complex problems in modern society, beginning with how children master the computer or adapt themselves to a new environment when their family moves house, and ending with how large teams of highly qualified specialists try to implement cutting-edge projects in space, nuclear, military, scientific fields, the humanities and so on. A vivid example of a complex problem is the way the work of the The Large Hadron Collider is organized. That project involves many specialists across the world and solves a multitude of interconnected problems and tasks from high-level unanswered scientific questions (which is the whole rationale of the project) to the tasks of ensuring various types of security, logistics, organizing meals for all the staff, etc., to mention just some problems at random.

I.A.Vassiliev (2004) writes that in Russia one of the earliest psychological approaches to the analysis of complex problem solving was tried by B.M.Teplov in his paper “The Military Commander’s Mind” published in 1945 (reprinted: Teplov, 1985). The tasks solved by a military commander waging war are of course complex.

Later the problems of solving complex tasks were studied by the research school of operative thinking led by V.N.Pushkin, the operative intelligence school of D.Dörner, the implicit learning concept in controlling dynamic systems by D.Broadbent and D.Berry, the meaning theory of thought by O.K.Tikhomirov, most notably in the works of one of its main representatives, I.A.Vassiliev, and in this writer’s concept of exploratory activities and creative thought in complex developing areas.

The following considerations lend relevance to studies in this field. The development of society is increasingly dynamic, with humanity creating and becoming involved in ever new, broader and more complicated networks of interactions (technological, economic, information-related, social, political, military, etc.). This prompts the need to understand how man solves the problems that require the simultaneous knowledge of many scientific and practical areas, intentions and actions of other people, i.e. partners, allies and enemies, the ability to tease out diverse information from a multitude of sources and to take many decisions at once within harsh time constraints, to control a multitude of interconnected new and diverse objects and phenomena at once. This requires that the subject to depart from the simple canonical “one-action–one-effect” (one cause–one consequence) scheme. What is needed is a different system of organizing cognitive activities, a system of a qualitatively higher level.

This area is studied by one of the most rapidly developing departments of cognitive psychology, the psychology of solving complex problems that require the study and control of complex dynamic systems.

To better understand the specifics of complex problem solving compared with decision-making, which is the subject of another area of cognitive psychology, one can turn to the highest achievement of the latter as represented by the works of Nobel Prize-winner D.Kahneman and his colleague A.Tversky with what has become classical examples. A participant is presented with a limited number of alternatives with clearly formulated characteristics (for example, in the Asian disease problem he is offered two methods of treating an epidemic and dealing with its consequences) and is asked to decide which method is to be preferred (Kahneman, Tversky, 2003). These works brilliantly demonstrate systematic violations of the rational logic of decision-making that occur even in spite of the fact that the problem has all the data for making the correct choice, that the data are few and clearly formulated.

The complex problem-solving area studies a different type of reality. The solver does not choose between available alternatives (like a customer chooses one type of washing powder among several displayed on the shelf), but invents and generates alternatives himself. He experiments, controlling new objects by trial and error, discovers new properties, connections and regularities, etc.

To illustrate the difference between these approaches let us use two versions of the game of chess, the classical and the modified. The classical chess game is an example of sequential decision-making: the player, proceeding from the observed position of the chess pieces on the board, chooses the optimal move, one of a finite (albeit a very large) number of variants. It has been proven that there exists a winning algorithm for such a choice (the chess game winning algorithm).

However, D.Dörner argues, imagine that you are playing chess on a board of a very large size, much of which is covered in fog, against an unknown number of players. It is not quite clear who your opponents and, who your partners are and by what rules each of them is playing. Furthermore, all the chess pieces are tied together by invisible rubber threads so that moving one of them causes unpredictable movements of others. A complex problem at its early stages of solution can be compared to such a “blindfold” game and it differs in a fundamental way from the gambit in a classical game of chess with a known set of chess pieces and a single opponent. For complex problems there are no and cannot be algorithms with the help of which to calculate the alternatives and choose the best one[[2]](#footnote-2). The solution of complex problems calls for a range of diverse capabilities: cognitive (the ability to experiment, glean information from a multitude of sources, process it within a short time and make several decisions simultaneously), personal and emotional (the ability to act in new and undefined conditions, inner readiness for various results of actions, including unexpected-both positive and negative – results), social skills connected with understanding and taking into account the intentions and actions of many people – partners, allies and opponents.

Thus, complex problem-solving and decision-making are two distinct areas dealing with different aspects of reality and complementing each other. Even as the Kahneman and Tversky school investigated biases in irrational decision-making, the Dörner school studied errors in the generation of alternatives, unreasonable experimenting, mismanagement of goals, etc. It is not for nothing that his 1987 book is called *The Logic of Failure.* (English and Russian translations from German were in 1997, *see* Dörner, 1997.)

Like in other areas of science, the boundary between these two complementary approaches is not watertight. Thus the “naturalistic decision-making” trend which deals with decision-making in real extreme situations dates back its official history to the analysis of the causes of the disaster that occurred on July 3, 1988 when the American cruiser *Vincennes* off the coast of Iran shot down an Iranian passenger plane with 290 passengers and 16 crew members having mistaken it for an Iranian fighter bomber preparing to attack. Some key provisions of that area of study are very close to the complex problem-solving area, which warrants combining the two under a general umbrella term “complex cognition” (Funke, 2010; Klein, 2008; Knauff, Wolf, 2010; Lipshitz et al., 2001).

To go back to PISA. In various years it included decision-making tasks (let us call them Kahneman problems)[[3]](#footnote-3). In 2012 complex problems were introduced. Let us call them Dörner problems because the designers explicitly recognized that they proceeded from Dietrich’s Dörner’s research in developing PISA 2012 assignments. These are interactive (i.e. experiment-based), dynamic and multifactor problems. Some of the more complicated computer scenarios developed by this research trend use such objects as, for example, a virtual factory, a city or a state with thousands of unknown internal links, with the participant having to sort out at least part of them in order to control the system with a measure of success (Dörner, 1997). One can reasonably suppose that the many modern strategic computer games such as SimCity, Civilization, etc. are partly based on the research by Dörner (“Tanaland”, “Moro”, “Lohhausen”, etc.) that have been conducted since the 1970s. The similarity has been directly stated (Riegler, 1998, p. 43). Even if these computer games were devised later and quite independently (which is improbable) the parallel indicates that the direction in which culture (science, mind games) are moving is not accidental. The school of O.K.Tikhomirov also began using such complex scenarios (Lysenko, 1989).

The list of scientific ideas that underlie the complex problem solving trend has been described in detail by this writer (Poddiakov, A., 2002, 2006b; Poddiakov & Eliseenko). Only some of them will be noted here.

The complex problem solving area is part of the complexity sciences which have burgeoned in recent decades and use the mathematical apparatus of the complex dynamic systems theories. These sciences of the complexity and dynamics of systems develop the holistic and not reductionist approach[[4]](#footnote-4). Their apparatus is capable of working constructively, without falling into excessive determinism or agnosticism, with the concepts of uncertainty, instability, and unpredictability and to consider multiple interactions. These sciences sprang up in the 20th century as an attempt to overcome the limitations of the scientific approaches of the Modern Times whose ideal has been Euclidean geometry, Newtonian mechanics and the determinism of Laplace and which now are considered to be reductionist (simplifying reality to the point of forcibly subjugating it to one or several principles, formulas and axioms). According to Nobel Prize-winning scientist I.Prigogine, at the time science was dominated by the “illusion of the universal”, the illusion of the possible existence of a single, “divine” vantage point “which offers a view of the entire reality” (Prigogine, Stengers, 1986, p. 289). Both an advantage and a shortcoming of the reductionist approach and the static, invariant-type systems it generates is the fact that they create more unambiguous, simple, and inherently non-contradictory models of reality. The fundamental weakness of such invariant systems is the unbridgeable gap between the infinite variety of the changing reality and the idealizing conceptual unity, simplicity and accuracy (Gloy, 1994).

Those who design interactive complex problems introduce into their content the modern ideas of complexity sciences: on internal dynamics and lack of total predictability of the behavior of complex systems; their non-transparency (important properties, links and regularities cannot be directly observed); the multiplicity of goals that arise in managing such a system (polytely), the inevitability of spin-off results linked in a complicated way with the original goals; etc. PISA 2012 does it of course selectively and on a limited scale since the interactive problem was only one among many items which had to be solved within 15-20 minutes. The designers faced a complex psychological and pedagogical task (or even a complex problem): to create an object that could be explored and understood by students within a limited time and that would nevertheless fit the description of complex problems, i.e. would be a “minimally complex item”, and yet be valid in diagnostic terms as an instrument of educational assessment (Greiff et al., 2013).

The PISA 2012 interactive problem preserves at least two key properties of complex systems: non-transparency (i.e. incomplete set of starting data which need to be gathered independently through trial and error), and multiple-connectedness. In the control theory, “multiply-connected” objects and systems are ones in which this or that parameter depends simultaneously on several, or one parameter determines several others. (In contrast, in “one-to-one-connected” objects any parameter is linked with one and only one other parameter.) Multiple-connectedness is observed in many natural phenomena, in the work of complex technical systems, in the economy, social life, etc.

The PISA 2012 interactive assignment did not reproduce such characteristics of complex systems as internal dynamics, diversity of areas of knowledge required for a solution, multiplicity of participants in the solution, etc. Some of these will be implemented in PISA 2015.

Let us now describe and analyze the interactive problems offered by PISA 2012 and PISA 2015.

**PISA 2012 and PISA 2015 interactive problems**

Both 2012 and 2015use a common methodological principle: psychologists construct a mini-model of a complex system and ask the student to master it independently. What is assessed is to what extent the teenagers have used certain cognitive strategies (for example, the strategies of multi-factor experimenting), what they have understood about the object, whether they can control it, etc. PISA 2015 will use a far more complex object than that of 2012 and the complex problem will be solved not individually (the student one-on-one with the object) but in a collaborative manner jointly with a partner. Now only the samples of such problems can be found in publications (final reports containing description of actually used items are not published yet), but these samples lend themselves to a substantive analysis.

***Instance of a PISA 2012 interactive task: “MP3-player” [[5]](#footnote-5)***

The problem has gone through preliminary tests, it has actually been solved by participants of pilot samples before it was published as a specimen. The designers write that they modeled one of the currently most common situations involving the solution of an interactive problem: an attempt to independently figure out how a new gadget works without the instructions.

The introduction to the problem reads: “A friend gives you an MP3 player that you can use for playing and storing music. You can change the type of music, and increase or decrease the volume and the bass level by clicking the three buttons on the player (◁, 🞊, ▷)”. The computer screen shows a picture of the player (see Fig.) and the participant can use the mouse to click the buttons observing the modes that they switch on. (The player can play 3 types of music – pop, rock and jazz – at 6 levels of volume and 6 bass levels).



Fig. Demonstration version of the MP3 player offered to school students for exploration (<http://erasq.acer.edu.au/index.php?cmd=cbaItemPreview&unitId=21>)

Let it be noted from the start that the fact that the device has 4 control buttons and more than 20 windows reflecting the values of controlled variables shows that the player is a multi-connected object. The function of each button is not constant, but depends on the state of the device and on the sequence in which the buttons were pressed ahead of the experiment[[6]](#footnote-6). Thus the multi-connected non-transparent object must be explored as a “black box” by providing various combinations of inputs and observing the outputs on display windows.

The specificities of exploring such a multi-connected object are highlighted by comparing it with other types of experimenting. Thus, when computers were first being introduced in schools many of the problems developed were of the following type. By introducing certain numerical values of a single variable in a single window and observing the changes of values of the second variable in another window the student had to determine the type of mathematical dependence between the two variables. This is of course a kind of interactive task (involving experimenting with a “black box”), but it is not a complex one because it does not have *multiple interactions and mutual influences.* But when there are only three variables at the input and about two dozen variables at the output, when combinations of actions are required and the effect of one controlling variable depends crucially on the combinations of other controlling variables (like in the player problem) the task of exploration and control becomes complex (more accurately, minimally complex).

PISA 2012 offers the student 4 items referring to the player.

*Question 1* (the problem solving process assessed is exploring and understanding) (PISA 2012.., 2013, p. 132).

“The bottom row of the MP3 player shows the settings that you have chosen. Decide whether each of the following statements about the MP3 player is true or false. Select "True" or "False" for each statement to show your answer”. Here “students are given a series of statements about how the system works and asked to identify whether they are true or false” (Ibid.)

*Question 2* (the problem solving process assessed isplanning and executing) (Ibid.).

“Set the MP3 player to Rock, Volume 4, Bass 2. Do this using as few clicks as possible. There is no RESET button.”

Scoring

Full Credit: “MP3 player is set in 13 clicks or less so that the bottom row reads: Rock, 4, 2.

Partial Credit: “MP3 player is set in more than 13 clicks so that the bottom row reads: Rock, 4, 2”.

No Credit: Other responses (<http://erasq.acer.edu.au/index.php?cmd=getCodingGuide&unitId=&unitId=21>).

*Question 3* (the problem solving process assessed isrepresenting and formulating) (PISA 2012.., 2013, p. 133)

“Shown below are four pictures of the MP3 player’s screen. Three of the screens cannot happen if the MP3 player is working properly. The remaining screen shows the MP3 player when it is working properly. Which screen shows the MP3 player working properly?”

*Question 4* (the problem solving process assessed is monitoring and reflecting)(PISA 2012.., 2013, p. 133)

“Describe how you could change the way the MP3 player works so that there is no need to have the bottom button (◁).You must still be able to change the type of music, and increase or decrease the volume and the bass level”.

“This item is one of a small number of constructed response items and requires expert scoring. Full credit answers are those that suggest how the MP3 player might still operate with only one button. There is no single correct answer, and students may think creatively in devising a solution”.

Scoring

Full Credit: “Gives an answer that describes how the MP3 player could still operate with only one arrow button.

- Change the way the top button works so that once you reach the right side of the display, one more click takes you back to the left of the display.

- Using one arrow, each line cycles around e.g. Music-Volume-Bass-Music

- The right arrow could just take you back to the far left of the screen if you reach the rightmost entry – for example, once you are on “bass”, pushing the right arrow button could take you back to “Music”.

- The volume is set at 3 by default. If you want to change it to two or one, it could be set up so that when you click the middle button to set the volume, it defaults to one (the lowest setting). Then you can use the right arrow to change it to whatever you want.

- When you want to change a property and you move to the line it is on, it should default to the lowest setting for that property.

- Use the one arrow to go all the way round (in a circle)” (<http://erasq.acer.edu.au/index.php?cmd=getCodingGuide&unitId=&unitId=21>).

Only these 6 answers are accepted, and other responses are not accepted.

Having described these problems let us discuss and assess them. One can see a sequence of problems covering various aspects of the activities of exploring, controlling and improving the object. My own sense is that some of the questions are rather unexpected (they do not arise in the process of preliminary exploration), which is good because the student has to reinterpret earlier gathered information and construct new strategies. Such situations are ecologically valid (they reflect reality) and are important in terms of diagnosis.

The designation of the diagnostic functions of the items raise some questions. For example, it is unclear why item 1 (“Decide whether each of the following statements about the MP3 player is true or false”) is marked as an exploring and understanding item. Exploring and understanding are very broad concepts and all the items cited have to do with exploring and understanding. Is it the case that all the other items do not require understanding or require less understanding? It would be more reasonable to describe the first item as one for testing a hypothesis because the person here must experimentally test a proposition formulated by somebody to see if it is false or true. It is an item on hypotheses testing and not an item that requires the student to formulate his/her own hypotheses.

Likewise it is unclear why item 2 is billed as “formulating” although it does not require an explicit formulation, one has simply to choose the right picture out of four.

It is not quite clear why item 4 is said to be one for monitoring and reflecting and not creativity although it looks like a modification of one of Torrance’s creativity tests (on elaboration of toys) [Torrance, 1967, pp.110-118], and even the description of the assignment uses the word “creatively” (“there is no single correct answer, and students may think creatively in devising a solution”) (PISA 2012, 2013, p. 133).

The authors limit the number of correct answers for this item to six. What are the risks that among the 200,000 students there will not be one who manages to invent a 7th adequate method. There are such methods, and indeed there are several: to have the switch to the left side occur not after the far right position is reached (the answer envisaged by the designers), but from any position by double-clicking button ▷, or even double-clicking button 🞊, or simultaneous pressing of ▷ + 🞊. So, double (consecutive) clicks, or simultaneous pressing of two buttons are not envisaged at all. Yet it is a common ergonomic solution in modern technical devices (International… 2006; Poddiakov, A., 2011). I would hazard the suggestion that the authors were committed to an excessively literal interpretation of the example of universal bans formulated about 15 years ago: “at no point two buttons have to be pressed simultaneously” (Vollmeyer, Burns, 1999; quoted from Greiff, 2012, p. 52) and trust that ban. However, at present because multi-touch devices – smartphones, etc., -- have invaded daily life multiple simultaneous pressing of keys (the touchscreen, etc.) is taken for granted by a vast number of people.

Finally, it has to be noted that the test questions do not include one of the key questions in exploratory activities, the question “what will happen if…?” (i.e., the student is not required to make a prognosis). Of course the authors had to limit the number of questions. But a correct forecast of the system’s behavior when acted upon in a certain way is an indispensable component for understanding it. Many other methodologies within this research trend contain forecast items, but they have for some reason been omitted here.

The answers to all these questions may be given when the organizers of PISA 2012 publish their analytical materials (presumably at the end of 2013).

***Collaborative interactive problem in PISA 2015: “The Aquarium” as an example***

In 2015 the students will be offered *interactive and collaborative*tasks: the student will have to explore a new system jointly with another participant. For example, together they will have to select optimal parameters of water temperature, lighting and other characteristics of the environment in a new aquarium that would provide the best conditions for exotic-looking virtual fishes. Things are complicated by the fact that the participants do not communicate with each other directly but through a messaging system and each can see and manage only his part of the control panel and initially does not know the control parameters accessible to the other participant. They can be learned in the process of joint discussion in the chat room where the strategy of joint exploration of the new biotechnological system can also be planned and implemented. This problem implements the method of forming a team, the so-called jigsaw puzzle, with none of the participants having complete information on the problem or enough instruments to solve it; the participants have different information and material resources and the problem can only be solved by agreeing, exchanging information and pooling actions (i.e. joining parts of the puzzle that each of them holds together in a collaborative way).

One can see that this problem situation actualizes the ideas of modern concepts of collaborative exploratory learning. In accordance with these ideas, the material for study must be so constructed as to make possible the distribution of roles and exploratory actions of the participants. It should reveal the essential characteristics of the reality being studied and create opportunities for joint substantive discussions that deepen understanding (distributed learning, distributed experimentation, distributed cognition). In this country, beginning from the 1970s-1980s, the possibilities of such learning objects and environments have been studied under V.V.Rubtsov (Communication-oriented…, 1996). Among modern approaches abroad one can single the concept of the development of environments based on student cooperation to study complex areas proposed by M.Spector (M.Spector, 2001) because he proceeds from the Dörner school works. More detailed information on modern concepts can be obtained on the site Collaborative Learning and Distributed Experimentation (COLDEX, [www.coldex.info](http://www.coldex.info)), on the Computer-supported collaborative learning (CSCL) sites, and of course the information that is most relevant for PISA 2015 is presented in a multipage official document “PISA 2015: Draft Collaborative Problem-Solving Framework” (<http://www.oecd.org/pisa/pisaproducts/Draft%20PISA%202015%20Collaborative%20Problem%20Solving%20Framework%20.pdf>). I would suggest that an interested reader visit the site. Because of limited space let us merely state that in addition to diagnosing earlier components of the solution of interactive complex problem (exploring and understanding, representing and formulating, planning and executing, and monitoring and reflecting) competences of joint activity will also be diagnosed (establishing and maintaining shared understanding, taking appropriate action to solve the problem, establishing and maintaining group organization). This joint activity is fairly complicated because students must experiment with a multifactor system and then control it, and that requires that they at least agree on the procedure of varying the variables accessible to every student. For example, it is necessary to agree that at the experimenting stage while one participant varies a controlling factor accessible to him, the other participant keeps “his” controlling factors constant (i.e. merely observes and is not active as an experimenter), otherwise a mess of joint effects will arise which would be impossible to clear up. The participants then swap roles, etc. The document referred to describes the criteria for assessing this activity.

Finally, an intriguing piece of information: according to the plan, the partner for each of the students will not be a real student but a computer programme (a computer conversational agent, robot, bot) simulating human communication. It will ask questions, simulate lack of understanding, propose ways of solving the problem, express opinions and assessments, etc. The use of software and not a flesh-and-blood person, the authors argue, would provide a “partner” that is the same for all the participants and make it possible to use questions and remarks thought through in advance to stimulate the discussion, demonstrate lack of understanding, offering this or that solution, etc., i.e. make the process more governable and uniform in terms of control of variables. The behavior of a living partner is unpredictable, it depends on the temper and character of the person, the mood and some unpredictable situational factors, which would create serious difficulties for a rigorous testing procedure (PISA 2015…, 2013).

While the rationale for introducing a computer programme as a partner is clear, some questions may be asked. For example, how will the identity of different language versions of the programme for different countries be verified? Will it be stylized to speak like a teenager?

Another problem that arises is that of awareness: information on the use of computer programmes as partners in PISA 2015 problems is in the public domain. Can the original knowledge of this (“I am communicating with a bot”) influence the students’ behavior and strategies? If a student did not know about it in advance but it would dawn upon him gradually during the course of solution (as happens in Internet communication with a bot) can this have an impact on the course of solution? For example, the student may be sidetracked into solving his own task, “is it or is it not a bot”. Would it not make sense to warn the students that they would be dealing with a computer programme in order to create a level playing field? These questions may not be as significant as they appear today (by 2015 dealing with a bot will become routine in any of the countries assessed), but whether that will be the case will only be known in 2015.

**The openness of interactive tasks and the problems of assessment**

The authors of PISA interactive complex problems have themselves to solve a number (perhaps a host) of problems pertaining to various areas. For reasons of space we have an opportunity to dwell on only one of them which is of a critical character, namely, the problem of open problems assessment.

Traditionally, beginning from J.P.Guilford, there are open-ended and close-ended problems. He criticized intelligence tests because they were close-ended (i.e. they had the only correct answer that the author of the problem knows in advance) and introduced open-ended creative tasks that allowed of an unlimited number of creative and original solutions.

Let us evaluate interactive problems in terms of their openness of closeness.

Let us introduce the concept of *open-beginning problems in which the starting data and terms are not formulated clearly or completely, in an exhaustive way*. What is critical is that interactive problems have precisely such an open beginning. The student constantly adds new information and revises earlier data during the course of real interaction with the object[[7]](#footnote-7). But how to assess this independent and creative search aimed at extracting information from a new object and building the knowledge about it that do not follow from clearly formulated terms? If, in exploring the virtual computer world, one student decides at the beginning to sit at the controls of a virtual plane, another at the controls of a virtual submarine and a third initially proceeds to make a chemical analysis of the environment, how can these strategies and results be compared?

*An ideal experimental object offered to a participant for independent cognitive activity is an object with an infinite number of different-level hidden elements, properties and links ranging from those that can be easily discovered and are almost evident to ones that are extremely hard to discover and understand*. The activity modeled in such an experiment amounts to a cognition by the subject of a complicated diverse world gradually cognized at ever new levels while it can never be understood completely (there is always a chance that a complex dynamic system will spring a surprise).

Interactive objects used to diagnose a solution of complex problems must create for the student conditions that are uncertain and novel enough to initiate and “kick-start” a creative exploratory behavior and give scope for it. But the uncertainty of conditions results in uncertainty of the range of abilities and skills that a student may try to call on in his activities. *The high level of uncertainty and novelty provides the student with freedom and a wide range of choices.* This is a merit, but also a demerit because the criteria of assessing the performance of the students inevitably become somewhat uncertain and constantly require new interpretations.

The problem is not all that acute while the test situations are confined to exploring a virtual player with three buttons. But the authors of PISA interactive problems have already been pointing out that taking into account the individual differences of the strategies chosen by different students, understanding the individual strategies not as errors of deviating from the known and predetermined method of solution is a problem so serious that the authors expect that its future solution within PISA would make a substantial contribution to the latest methodologies of data mining (Greiff et al., 2013; Müller et al., 2013). In terms of data mining things look as follows. At least 200,000 participants (and later millions) are solving a problem that allows of the use of various strategies. These students use different sequences of actions, with some actions performed more quickly than others while still others require a pause for thinking, and the authors must register all this. (Because it is impossible to record everything what is to be registered must be decided in advance.) Next in the processing of resulting body of data the question arises, how to differentiate the classes of various strategies? Should the differentiation be based on given rigid criteria or on flexible criteria that are modified as the system processing them is learning, so as, for example, to take into account the surprises that several talented students may spring by finding strategies not previously envisaged by the authors of a rigid system? Is it necessary to detect the possible out-of-the-box solutions by the students and if so how to do it considering the huge body of data? And how to assess what has been detected?

This brings us to the problem that has not been finally solved in creativity tests and which seems to have been inherited by large-scale assessment of the solution of complex problems. *The essence of creativity is to go beyond the framework of what is given and known, to go beyond the limits set by standards whereas a test is a standard procedure of assessment according to a set of parameters given in advance. Thus a creativity test should be a standard to measure the ability to act in a non-standard, novel way (be a “standard of measuring the non-standard”, a model of novelty for many years)*. *The creative acts demonstrated by a person (i.e. the novelty and non-standard nature of his/her decisions) must fit that standard* (Poddiakov A.N., 2004; Poddiakov, 2006a, 2006b).

For example, *Torrance Tests of Creative Thinking* fixes a scale of originality of possible answers (from 40 to 160 points) beyond which, the designers are sure, none of the students can rise. And indeed they will never be able to because the procedure of obtaining and processing data would not allow it. (It is as if two high-jumpers who have cleared respectively 5 and 8 meters were told that they had the same result: “Well done, it’s 3 meters” because the judges do not have a longer measuring tape.) This is a shortcoming of the originality test and its differentiating power that prevents us from considering this test to be perfectly valid. The validity is such that the test, if anything, does not make it possible to compare the originality of out-of-the-box answers, and yet it is such answers that are the most interesting in creativity tests.

The Torrance test stands in a better case than PISA 2012. In the former any answer that the experimenter considers to be outside the prepared list gets the highest score. The thinking behind it is: “The student has thought of something that has never occurred to anyone before, he has done a good job, let us give him the top score within the established ceiling.”

The designers of PISA award not the highest, but the lowest score to all the deviations from their list equating it to failure to provide a solution. This is in odd contrast with their earlier proclaimed value of individual solutions and the declaration that a deviation is not necessarily a mistake, the ideology of “open-ended” problems. Naturally, in addition to the 6 variants of answers to a creative assignment there are at least three unaccounted-for types (simultaneous pressing of two buttons or successive double clicks) and there is a multitude of other solutions.

The problem with this paradigm of assessment is as follows. The chosen test criterion of assessing creative activities – “a standard list of creative answers” is an oxymoron. (To put it mildly, it is a forced palliate, but then it should explicitly be recognized as a palliate). Using a standard list of creative answers prepared in advance we find ourselves in a paradoxical situation: the more novel and original a participant’s answer the less likely it is to be noticed and appreciated by the experimenter for the simple reason that the list of answers against which the experimenter compares answers does not contain as much as a hint at such an answer. Truly original solutions have a way of not being on the list of already known answers, but of enlarging it.

To be sure, a diligent experimenter, when confronted with a new answer that looks reasonable and yet is not on the standard list, may think and send it to the head office to the designers of the test who would decide how to evaluate and standardize the innovation. It may even happen that the answer would be included in an updated list of answers extending it by one unit (a feather in the participant’s cap). But this is no guarantee that the following morning another person would not come up with a new solution and his answer would pass unnoticed or be misinterpreted.

According to V.A.Lefebvre, psycho-diagnosis is the exploration of a system comparable in its perfection to the explorer (Lefebvre, 2003). In such cases an exhaustive exploration is impossible because to be able to fully explore another’s mind one must have a still more powerful mind that “stands above” the former and encompasses it. This rule cannot always be fulfilled in the practice of large-scale psycho-diagnosis as the person tested may turn out to be more intelligent than the experimenter. To appreciate the answer of future Alan Turings, William Rosh Ashbys and Albert Einsteins, one has recruits experts of comparable stature in order to notice and appreciate the innovation proposed. But where does one recruit enough such experts for 200,000 students being tested? The possible answer to the effect that “there is no need to recruit such experts because in a large-scale assessment of educational achievement we are not scouting for talents, but assessing country data” looks understandable, but still a palliate. One should spare a thought for the future Turings and Ashbys who probably got a 0 score in a creativity test when studying a new computer system. Is there a solution to this problem? Perhaps we will know, partly thanks to the next PISA rounds. But we believe that the paradigm of assessing creative answers in accordance with a list of criteria prepared in advance needs to be changed.

With luck, the results obtained from interactive PISA problems would help to revise or adjust the data and perhaps raise new questions about the relationship between tests of different types – intelligence tests, creativity tests and tests of exploratory behavior. (An analysis of their possible relationship at this point in time will be found in Poddiakov A.N., 2012).

**Constructing complex problems: part of a new educational environment and a development variable**

***Translating the content of complexity sciences into the content of education***

The ideas of complex reality that are then translated into education are based, on the one hand, on the theoretical provisions of mathematics, natural and engineering sciences, and on the other hand, on psychological analysis of what D.Dörner calls the *logic of failure of strategic thinking in complex situations* including the psychological analysis of past and ongoing (man-made and humanitarian) disasters.

Let us cite an example of how the young generation may get an idea of the complexity of mathematics. The film *The Oxford Murders* (2008) adapted by Alex de la Iglesia from a novel by the Argentine writer and mathematician Guillermo Martinez, has a plot that grows on you. A mathematics student (played by Elijah Wood, an idol of the young generation who appeared as Frodo Baggins in a cult movie *The Lord of the Rings*) becomes involved in the investigation of mysterious murders and in parallel in a romantic-erotic affair. As the plot unfolds the audience is exposed to lengthy dialogues between the mathematicians. Among the topics they discuss:

- at the start of the use of the large-scale intelligence assessment some students offered a non-standard solution to the standard problem of continuing a numerical set, the solution was not envisaged in the test but it fitted neatly with the numerical sequences;

- in general, for any finite set, an infinite number of legitimate continuations can be devised (this is directly connected with the plot in which the murderer each time leaves a sequence of symbols on the scene of every new murder, a sequence that is mysterious and grows constantly longer and needs to be explained);

- Kurt Gödel has proved the theorem about incompleteness of formal systems (i.e. within any abstract system of derived knowledge, however high its level, beginning from a certain level of complexity there are always true propositions that cannot be proved within that system, and false propositions that cannot be refuted within that system; these true propositions can be proved and false ones can be rejected only in the framework of a more complicated and powerful system which in turn has its true unprovable and false irrefutable propositions, etc.; and the original system may have an infinite number of diverse and more powerful continuations).

And that is not all. The characters speak about Wittgenstein, the Fermat theorem, etc. The young members of the audience are thrilled by the adventures of their favourite actor. Meanwhile the psychologist, teacher or mathematician concerned with the problem of education is thrilled to see how complex mathematical ideas can be presented.

Less spectacularly, there are more and more lay people who are not specialists in systems dynamics who learn about the “butterfly effect” from popular science journals.

A young person can find examples of multiple determination in popular articles on biology which write that a certain external phenotype or behavior pattern is controlled (influenced) by a multitude of genes, and that one and the same gene is involved in forming not one, but a range of phenotypes and behavior patterns (Markov, 2008). Incidentally, this example fits in exactly with the concept of multi-connectedness and perhaps one of the future interactive problems will have to do not with the life of exotic fishes in a fish bowl, but virtual experimenting with their genes and observation of the consequences.

Examples can be multiplied. All these are parts of the global civilization project that can be described as “exploring complexity” to use the title of a book by I.Prigogine. One of his next books was called *The End of Certainty.*

Let us now turn to psychology before going back to PISA.

***“Experimenting with experimenting”: autocatalytic effect in civilization project***

The ideas of complexity and how to study it have also been vigorously developed in psychological science. In the context of this article it is important that along with analytical problems (and intelligence tests patterned on analytical problems) the theory and methodology of open tasks has been developed: they are more complex to design and interpret than closed problems and they immerse a participant into a more complex environment. In other words, along with the study of “Kahneman uncertainty” solutions (with the choice between several clearly formulated alternatives) a study has begun of thought activity in the context of “Dörner uncertainty”. The latter implies generation and building of all the components in the hierarchy of activity (goals, tasks, hypotheses, means, strategies, etc.) in a complex environment replete with hidden connections and responding to external stimuli. The participant can potentially study such an environment endlessly, if only because the environment itself changes and develops. Environments of this type, when used for educational purposes, can, in our view, form an important part of the “school of uncertainty”, according to A.G.Asmolov, a school of living in uncertain situations as non-standard, variant education in a changing world (Asmolov, 1996).

The methodology of open problems was implemented in several only partly overlapping areas:

- in methodologies of experiments and tests of creativity (with a closed beginning and open end) where one is required to come up with creative solutions of a problem with terms formulated by somebody else;

- in experimental methodologies and tests of exploratory behavior (with an open beginning and an open end) which studies the independent behavior described above that unfolds in an environment with new and complex objects without “others” setting goals and tasks, i.e. the person sets the goals and tasks of exploration and management himself, generates hypotheses, etc.

A whole area of study has emerged that can be described as “experimenting with experimenting”: a person (a child or a grownup) is offered for independent exploration and experimenting specially designed new technical objects that are complex (at least for the person tested) and entire artificial environments and then the regularities and features of this cognitive activity are studied. Not all these objects were constructed as multi-connected ones containing networks of interacting factors. But as early as 1966 the outstanding psychologist and educationist G.Bruner wrote that “one can indeed imagine kindergarten games designed to make children more actively alert to how things affect or connected with each other, a kind of introduction to the idea of multiple determination of events in the physical and the social world” (Bruner, 1966, p. 27). Whether under the impact of this pronouncement or independently from it, such games began to be devised in various countries and for various age groups. They include computer scenarios for complex multi-factor reality by D.Dörner developed since 1970s; computer micro-worlds of L.Schauble and R.Glaser that enable students of various age to experiment with designs of virtual race cars, economic objects and observe the effects of the interaction of factors (Schauble, Glaser, 1990); etc. It is hard to give the exact number of such computer methodologies because by no means all of them are indexed since they are often developed with a specific practical task in mind (for example, a specific task of vocational training).

One important issue is the relationship between virtual and real objects (more broadly, the model and the reality) in the study of complex problem solutions. On the whole it can be said that the use both of virtual and real objects has its advantages and disadvantages, so that objects of both types should be used. As regards the development and use of real multi-connected objects (as opposed to those simulated on a computer screen) I can cite my own studies pursued since the mid-1980s. I have constructed multi-connected puzzle toys, “black boxes” of various degrees of non-transparency and complexity, to see how they are explored by preschool and school-age children, how they invent for themselves the strategies of multi-factor experimenting and how they understand multi-factor interactions. In the context of comparison with the object used in PISA 2012 what is important is that the main method of introducing multi-connectedness into the object that is understandable to a child was a special type of poly-functional keyboard (or multi-touch keyboard one finds in modern household appliances). Simultaneous pressing of several buttons resulted in effects that differed dramatically from the effects of pressing the same buttons one by one, with the function of each button changing depending on the combination with other pressed buttons. Indeed, work with real multi-connected objects suggested to me some possible solutions to the creative problem of improving an MP3-player that have not been taken into account by the designers of PISA, but are common in modern-day real gadgets. Reality is richer than the model because a model is abstracted from a multitude of real properties in order to be a model, but the ignored properties may make a great difference in practice.

One of the shortcomings of the use of real objects for diagnostic purposes is that they cannot be produced for large-scale testing (involving hundreds of thousands of people, like in PISA), especially if the object is truly a complex system. In this case computer simulation has an indisputable advantage: “virtual objects” of any degree of complexity can be emailed to all the participants or uploaded to a generally accessible server, if shortcomings are discovered they can be modified and mailed (uploaded) again, and to this one must add the possibility of simultaneous large-scale registration of test data and the subsequent computer processing.

So far, however, the ordinary consumer in his daily life and the professional in his work deal with thoroughly material technical objects (a virtual washing machine or a virtual rocket are of little use) and these systems have real, and not simulated unpredictability and complexity, so that the use of real objects for psychological experiments would make sense. This is only one of the more obvious considerations; we cannot dwell on others for lack of space.

On the whole the deployment of theories, experiments, practical diagnostics and education connected with free exploratory behavior, the setting and solution of complex problems has implications not only for education but also for culture and, let us face it, for civilization. Initially, around the 1950s-1960s psychologists in various countries became aware of and formulated the value of these types of cognitive activities and started constructing experimental objects to study them and to devise experimental procedures, initially in a few laboratories. The participants (children and adults) experimented with these objects and devised “theories”, explanations of their work, some of which were more adequate than others. The experimenters were engaged in “second-tier” experimenting: they experimented with the experimenting activity, constructing ever new and more complex objects and systems, new terms and procedures for their use and used the data obtained to formulate their own theories of cognitive activity, invented complex mathematical models (for example, models of non-linear development dynamics), etc. Thanks to experimenting with experimenting, which continues to this day, scientists obtain new facts and modify their ideas of the regularities of cognitive activity and its development and methods of stimulating that development.

So, there is not only interaction at the “participant ↔ object” level (the participant experiments with the object which responds to external stimuli changing the participant’s ideas). There is the less evident interaction at the “experimenter ↔ (participant ↔ object)” level. During the course of this interaction the experimenter’s cognitive structures change. He begins developing new methods and objects with which the participants experiment to discover new, previously unknown possibilities of cognitive activity, etc.

Finally, there is a third level of interaction (for now we have to confine ourselves to just three). This is interaction between “society ↔ {educators ↔ (participants ↔ objects)}”. Research achievements in the field of “experiments with experimenting” are introduced into public domain through a system of communications. One recent example would illustrate this. The noted American scientist A.Gopnik has published articles about experimenting of preschoolers with the objects she had designed in some key journals *Scientific American* (Gopnik, 2010) and *Science* (Gopnik, 2012) and an article from *Scientific American* has been translated into Russian in the Russian journal *V mire nauki*[[8]](#footnote-8). Some of the more important theses in these publications (known to older readers) are as follows: the cognitive abilities of preschoolers are underestimated, they are much higher than could be imagined, but the persons who make decisions on education policies systematically underestimate these capabilities. It is necessary to develop child activities such as exploration, experimenting and play. It is necessary to take advantage of children’s natural sense of curiosity because children are inborn scientists and their underestimated ability to test hypotheses and draw causal conclusions in order to mold their thinking. A.Gopnik’s articles are one of the recent and most notable examples, but there are others.

Such translation of research achievements changes society’s ideas:

- about the regularities and features of cognitive activities and the possibilities of its development;

- the possibilities complex objects, systems and models offer for such development.

Society reacts to all this by changing its demands, supporting theoretical studies and practical development of new diagnostic and didactic objects, environments and activities which influence cognitive development in a new way (for example, there is a joint project of nine European countries called *Creative Little Scientists* funded from the EU 7th Framework Programme, see <http://www.creative-little-scientists.eu>), etc., development spirals on and on, in chemistry this is called an autocatalytic process. We are today observing only one of the numerous results and so far this article provides a detailed analysis only of this result. This marks a transition to a qualitatively new level of institutionalization of the complex problem solving studies, the introduction of the corresponding interactive problems in the practice of large-scale educational assessment of school students with simultaneous development of new methods of the use of computer agents as partners in joint activities, data mining in the processing of results, etc. Specialists in all these fields must be trained[[9]](#footnote-9), various resources – intellectual, technological, etc. – must be formed and other multiple problems must be solved.

The situation is not unlike that described by the scientists involved in the creation of The Large Hadron Collider: at various stages of this megaproject the developers did not have the necessary means (for example, computer clusters) and indeed could not be sure whether they would be (or indeed could be) created because they were exploring uncharted areas and technologies. And yet The Large Hadron Collider has been created and is producing unique scientific results. Another similarity is that the PISA project and the complex problem-solving area are new growth areas. One can reasonably hope that they will together solve the complex meta-problem of introducing complex problems reflecting the complex, diverse poly-determined reality in the educational and assessment environment.

**References**

Asmolov, A.G. (1996). *Kul'turno-istoricheskaya psikhologiya i konstruirovanie mirov [Cultural-Historical Psychology and Construction of Worlds].* Moscow: Institut prakticheskoi psikhologii. (Russian).

Banta, T. (1970). Tests for the evaluation of early childhood education: the Cincinnati Autonomy Test Battery (CATB). J.Helmuth (Ed.), *Cognitive studies* (pp. 424-490). N.Y.: Brunner / Mazel Publishers.

Berry, D., & Broadbent, D. (1995). Implicit learning in the control of complex systems. In P.A. Frensch & J. Funke (Eds.), *Complex problem solving: The European Perspective* (pp. 131-150). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bruner, J.S. 1966. The process of education. Cambridge: Harvard University Press.

Dörner, D. (1990). The logic of failure. In Broadbent D.E., Baddeley A., & Reason J.T. (Eds.), *Human factors in hazardous situations. Proceedings of a Royal Society Discussion Meeting, Philosophical Transaction of the Royal Society. Series B, Biological Sciences. Vol. 327 (1241)*, 463-473.London, Oxford: Clarendon Press.

Dörner, D. (1997). The logic of failure: Recognizing and avoiding error in complex situations. New York: A Merloyd Lawrence Book.

Forman, G. (1986). Observations of young children solving problems with computers and robots. *Journal of Research in Childhood Education. 1986, 1(2),* 60-74.

Frensch P.A., Funke J. (Eds). (1995.) Complex problem solving: the European perspective. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Funke, J. (2010). Complex problem solving: a case for complex cognition? *Cognitive Processesing, 1 (2),* 133-142.

Funke, J. (2012). Complex problem solving. In N. M. Seel (ed.). *Encyclopedia of the Sciences of Learning.* pp 682-685. NY; Dordrecht; Heidelberg: Springer.

Gloy K. (1994). Problema poslednego obosnovaniya dinamicheskikh system [The Problem of Final Validation of Dynamic Systems]. *Voprosy Filosofii, 3*, 94-105. (translated from German into Russian).

Goode, N., & Beckmann, J. F. (2009). You need to know: there is a causal relationship between structural knowledge and control performance in complex problem solving tasks. *Intelligence, 38,* 345-352.

Gopnik, A. (2010). How babies think. *Scientific American, July,* 76-81.

Gopnik, A. (2012). Scientific thinking in young children: theoretical advances, empirical research, and policy implications. *Science, 337,* 1623-1627.

Greiff, S. (2012). Assessment and theory in complex problem solving. A continuing contradiction? *Journal of Educational and Developmental Psychology, 2(1).* 49-56.

Greiff, S., Holt, D., & Funke, J. (2013). Perspectives on problem solving in cognitive research and educational assessment: analytical, interactive, and collaborative problem solving. *The Journal of Problem Solving. 2013. Vol. 5(2).* 71-91.

Güss C.D., Tuason Ma.T., & Gerhard C. (2010). Cross-national comparisons of complex problem-solving strategies in two microworlds. *Cognitive Science, 34(3),* 489–520.

Hutt, C. (1970). Specific and diversive exploration. *Advances in child development and behaviour.* L.P.Lipsitt, H.W.Reese (Eds.). Vol. 5, pp. 119-180. NY: Academic Press.

*International Encyclopedia of Ergonomics and Human Factors.* 2nd ed. (2006). / W. Karwowski W. London: CRC Press, Taylor & Francis.

Kahneman, D. & Tversky, A. (2003). Ratsional'nyi vybor, tsennosti i freimy [Rational choices, values, and frames]. *Psikhologicheskii zhurnal*, *4*, 31–42. (translated from English into Russian).

Klein, G. (2008). Naturalistic decision making. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 50(3),* 456–460.

Knauff, M., & Wolf, A.G. (2010). Complex cognition: the science of human reasoning, problem-solving, and decision-making. *Cognitive Processesing, 11 (2),* 99-102.

Knyazeva, O.L. (1987). Osobennosti poiskovoi deyatel'nosti doshkol'nikov pri reshenii naglyadno-deistvennykh zadach [Exploratory Activity of Preschoolers in Solving Sensory-Motor Problems]. *Voprosy Psikhologii, 4*, 86-93. (Russian).

*Kommunikativno-orientirovannye obrazovatel'nye sredy [Communication-Oriented Educational Environments].* (1996). V.V.Rubtsov (Ed.). Moscow: Psikhologicheskii institut. (Russian).

Lipshitz, R., Klein, G., Orasanu, J., & Salas E. (2001). Focus article: taking stock of naturalistic decision making. *Journal of Behavioral Decision Making, 14,* 331–352.

Lysenko, E.I. (1988). Igra s EVM kak vid tvorcheskoi deyatel'nosti [Play with a computer as a creative activity]. Candidate dissertation (Psychology), Moscow. (Russian).

Markov, A. (2008). Geny upravlyayut povedeniem, a povedenie — genami [Genes Control Behavior, Behavior Control Genes]. Elementy.ru, 12 November, 2008. <http://elementy.ru/news/430913>. (Russian).

Müller, J., Kretzschmar, A., & Greiff. S. (2013). Exploring exploration: inquiries into exploration behavior in Complex Problem Solving assessment. *Proceedings of the 6th International Conference on Educational Data Mining*. [July 6-9, 2013; Memphis, TN, USA.](http://hdl.handle.net/10993/3175) S. K. D’Mello, R. A. Calvo, & A. Olney (Eds.). International Educational Data Mining Society, 2013. pp. 336-337. <http://www.educationaldatamining.org/EDM2013/papers/rn_paper_69.pdf>.

Osman, M. (2010). Controlling uncertainty: A review of human behavior in complex dynamic environments. *Psychological Bulletin, 136(1),* 65-86.

*PISA 2012 Assessment and analytical framework: mathematics, reading, science, problem solving and financial literacy*. OECD: OECD Publishing, 2013. <http://dx.doi.org/10.1787/9789264190511-en>.

*PISA 2015: Draft collaborative problem solving framework*. OECD, 2013. <http://www.oecd.org/pisa/pisaproducts/Draft%20PISA%202015%20Collaborative%20Problem%20Solving%20Framework%20.pdf>.

Poddiakov, A. (1990). Kombinatornoe eksperimentirovanie doshkol'nikov s mnogosvyaznym ob’’ektom – “chernym yashchikom” [Combinatorial Experimenting of Preschoolers with a Multi-Connected Object – Black Box]. *Voprosy Psikhologii, 5*, 65-71. (Russian).

Podd'iakov, A. (1992). Teaching preschoolers combinatory experimentation. *Journal of Russian and East European psychology, 30(5),* 87-96.

Poddiakov, A. (1994). Preschoolers' acquirement of competences in factor combining and factor interaction. In J.ter Laak, P.G.Heymans, & A.I.Podol'skij (Eds.), *Developmental tasks: towards a cultural analysis of human development* (pp. 173-186). Dordrecht: Kluwer Academic Publishers.

Poddiakov, A. (1998). O realizatsii printsipov razrabotki mnogofaktornykh ob"ektov dlya izucheniya myshleniya detei [Implementation of the Principles of Development of Multi-factor Objects for the Study of Child Thought]. *Vestnik Moskovskogo universiteta. Seriya 14. Psikhologiya, 2,* 31-42. (Russian).

Poddiakov, A. (2001). *Razvitie issledovatel'skoi initsiativnosti v detskom vozraste [Development of Exploratory Initiative in Childhood].* Doctoral Dissertation (Psychology) Moscow, 2001. <http://www.phido.ru/Disser/16295/View.aspx>. (Russian).

Poddiakov, A. (2002). Reshenie kompleksnykh zadach [Complex problem solving]. In: V.N.Druzhinin & D.V.Ushakov (Eds.), *Kognitivnaya psikhologiya* (pp. 225-233). Moscow: PER SE. (Russian).

Poddiakov, A. (2004). Psikhodiagnostika intellekta: vyyavlenie i podavlenie sposobnostei, vyyavlenie i podavlenie sposobnykh [Psychodiagnosis of Intellect: Revealing and Suppressing Abilities, Revealing and Suppressing Talent. *Psikhologiya. Zhurnal Vysshei shkoly ekonomiki, 4,* 75-80. (Russian).

Poddiakov, A. (2006a). Ambivalence and cognitive heuristics for dealing with ambiguity in complex social worlds. *Estudios de Psicología, 27. 1,* 101-116.

Poddiakov, A. (2006b). Issledovatel'skoe povedenie: strategii poznaniya, pomoshch', protivodeistvie, konflikt [*Exploratory Behavior: Cognitive Strategies, Help, Counteraction, and Conflict].* Moscow: PER SE. (Russian).

Poddiakov, A. (2007). Ovladenie metodologiei mnogofaktornykh issledovanii kak napravlenie poznavatel'nogo i lichnostnogo razvitiya [Mastering the Methodology of Multifactor Research as an Area of Cognitive and Personal Development]. In: A.S.Obukhov (ed.), Issledovatel'skaya deyatel'nost' uchashchikhsya*.* Theory and Methodology (pp.166-177). Moscow: Issledovatel. (Russian).

Poddiakov, A. (2011). Didactic objects for development of young children's combinatorial experimentation and causal-experimental thought. *International Journal of Early Years Education, 19(1),* 65-78.

Poddiakov, A. (2012). Komplikologiya: sozdanie razvivayushchikh, diagnostiruyushchikh i destruktivnykh trudnostei dlya drugikh sub"ektov [Complicology: creating developing, diagnosing and destructive difficulties]. *Soderzhanie, formy i metody obucheniya v vysshei shkole: Analiticheskie obzory po osnovnym napravleniyam razvitiya vysshego obrazovaniya, 10,* 1-80. (Russian).

Poddiakov, A. (2013). Metodika prepodavaniya uchebnoi distsipliny «Psikhologiya issledovatel'skogo povedeniya i resheniya kompleksnykh zadach» [Methodology of Teaching the Discipline “Psychology of Exploratory Behavior and Complex Problem-Solving”]. *Psikhologiya v vuze, 2,* 87-111. (Russian).

Poddiakov, A.N., & Eliseenko, A.S. (2013). Svyazi sub"ektivnoi neopredelennosti i effektivnosti resheniya kompleksnoi problemy (na materiale deyatel'nosti upravleniya virtual'noi fabrikoi) [Relations between subjective uncertainty and performance in complex problem solving (based on the management of virtual factory)]. *Psikhologicheskie issledovaniya, 6(28).* <http://psystudy.ru/index.php/eng/2013v6n28e/794-poddiakov28e.html>. (Russian).

Poddiakov, N.N. (1961). Osobennosti orientirovochnoi deyatel'nosti u doshkol'nikov pri formirovanii i avtomatizatsii prakticheskikh deistvii [*Orientating Activity of Preschoolers When Forming and Automating Practical Actions: Candidate’s Dissertation (Psychology).* Moscow. (Russian).

Poddiakov, N. (1985). Novye podkhody k issledovaniyu myshleniya doshkol'nikov [New approached to investigation of preschoolers’ thought]. *Voprosy psikhologii, 2,* 105-117. (Russian).

Poddjakow, N. *Die denkentwicklung beim vorschulkind*. Berlin: Volk und Wissen Volkseigener Verlag, 1981. (German).

Prigogine, I., & Stengers, I. (1986). Poryadok iz khaosa [Order Out of Chaos]. Moscow: Progress, 1986. (translated from English into Russian).

Quesada, J., Kintsch, W., & Gomez, E. (2005). Complex problem-solving: a field in search of a definition. *Theoretical Issues in Ergonomics Science, 6(1),* 5-33.

Riegler, A. (1998). “The end of science”: can we overcome cognitive limitations? *Evolution and Cognition, 4 (1),* 37-50.

Schauble, L., & Glaser, R. (1990). Scientific thinking in children and adults. In D. Kuhn (ed). *Developmental perspectives in teaching and learning thinking skills*. Contrib. Hun. Dev. Basel, Karger. Vol. 21. P. 9-27.

Shragert, J., & Klahr, D. (1986). Instructionless learning about a complex device: the paradigm and observations. *International Journal of Man-Machine Studies, 25,* 153-189

Spector, J. M. (2001). Tools and principles for the design of collaborative learning environments for complex domains. *Journal of Structural learning and Intelligent Systems. 14 (4)*, 483-510. (Russian).

Teplov, B.M. (1945/1985). Um polkovodtsa. [The Military Commander's Mind]. In: Teplov, B.M. *Izbrannye Trudy*, Vol. 1, pp. 223-305. Moscow: Pedagogika. (Russian).

Torrance, E.P. *Education and the creative potential*. Minneapolis: The University of Minnesota Press, 1967.

Vassiliev, I.A. (1998). Motivatsionno-emotsional'naya regulyatsiya myslitel'noi deyatel'nosti [Motivational-Emotional Regulation of Thought Activity]. Doctoral dissertation (Psychology), Moscow. (Russian).

Vassiliev, I.A. (2004). Spetsifika myslitel'noi deyatel'nosti cheloveka v slozhnykh situatsiyakh [Human Thought Activities in Complex Situations]. In A.N.Gusev, V.D.Solovyov (eds.). *Materialy Pervoi Rossiiskoi Internet-konferentsii po kognitivnoi nauke*  (pp. 136-141).Moscow: UMK "Psikhologiya". (Russian).

Veraksa, N.E. (1981). Osobennosti preobrazovaniya protivorechivykh problemnykh situatsii doshkol'nikami [Transformation of Contradictory Problem Situations by Preschoolers]. *Voprosy Psikhologii, 3,* 123-127. (Russian).

Vollmeyer, R., & Burns, B. D. (1999). Problemlösen und Hypothesentesten [Problem solving and hypothesis testing]. In H. Gruber, W. Mack & A. Ziegler (Eds.), *Wissen und Denken. Beiträge aus Problemlösepsychologie und Wissenspsychologie* (pp. 101-118). Wiesbaden: Deutscher Universitäts Verlag.

1. A simple rule-of-thumb for distinguishing these two types is whether the problem can be solved mentally directly after reading the terms (in other words, whether a person can solve it by closing his eyes to avoid being distracted and putting his hands behind his back immediately after reading the terms). If the answer is yes, this is an analytical problem. If he has to look for some previously unknown information while exploring the object and experimenting with it (hands are needed to manipulate the object and eyes to observe what is happening) then this is an interactive problem. [↑](#footnote-ref-1)
2. This is because on the one hand, complex problems always include initially ill-defined sub-problems and sub-tasks (for example because the activity is new) and hence do not allow of the use of rigorous algorithms, and on the other hand, because some of the sub-tasks formulated clearly turn out to be algorithmically undecidable, which is often not clear to the person confronted with such a phenomenon. [↑](#footnote-ref-2)
3. One brilliant problem required a 15-year-old to sort out the list of tariff options of a communications operator simulating a situation when the solver has all the information, but the options are so cleverly presented as to provoke the choice that benefits the operator out of the alternatives generated by him. [↑](#footnote-ref-3)
4. One of the precursors (or even foundations) is thought to be “Tektology” by A.Bogdanov published a hundred years ago in 1913. [↑](#footnote-ref-4)
5. Perhaps some readers would choose to do the problem before reading the description and analysis. It is available on the site <http://erasq.acer.edu.au/index.php?cmd=cbaItemPreview&unitId=21> [↑](#footnote-ref-5)
6. Such a keyboard is called polyfunctional (or keyboard with multifunctional buttons). Its widespread use in day-to-day devices was made possible by the development of technology; only several decades ago people had to deal with devices operating on the principle “one button (switch) – one reacting element (lamp, motor, etc.)”. You may note (recalling some old appliance) that for these appliances questions such as “what knob regulates volume? Which one regulates low frequencies? What switch regulates wavelength (in a radio)?” made sense. For many modern devices these questions make no sense: three or four buttons control a multitude of functions; thus people are constantly exposed to technical multi-connected objects in their daily life. [↑](#footnote-ref-6)
7. The participant who received an intelligence test item would be thought to behave oddly if he asked the facilitator how the starting data had been obtained or questioned their authenticity. In real cognitive activity such questions are absolutely legitimate. [↑](#footnote-ref-7)
8. A translation error has crept in. The Russian translation of the subtitle reads: “Even very little children know much more, explore the world much deeper and learn far more fully than psychologists imagine” (translated from Russian, <http://sciam.ru/journal/catalog/10-2010>). In the English original the subtitle refers not to psychologists, but to scientists in general, and then only to their ideas in the past (<http://www.alisongopnik.com/papers_alison/sciam-gopnik.pdf>). Psychologists, of all people, know what is happening in this field better than others (they themselves are carrying out these investigations). For example, readers in Russia can learn much about the creative experimenting of preschoolers, whose importance is stressed by A.Gopnik, from the works of N.N.Poddiakov (1985) (or Poddjakow, in other spelling) and the members of his school, N.E.Verkasa (1981), O.L.Knyazeva (1987) and others. [↑](#footnote-ref-8)
9. For example, the course “Psychology of Exploratory Behavior and Complex Problem Solving” is a part of an MA programme “Measurements in Psychology and Education” introduced at National State University Higher School of Economics (Poddiakov, A., 2013). [↑](#footnote-ref-9)