Digitalization of diagnostics of cognitive strategies for designing puzzle objects

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Abstract. This research describes an instrumental method for studying the activity of students in problem solving, based on the use of dynamic computer tests (simulators) to diagnose cognitive strategies for designing puzzle objects. The proposed instrumental method allows to experimentally obtain actiograms of actions that graphically display human activity in finding solutions to problems. Actiograms of actions or trajectories of educational activities reveal individual differences in the ways of obtaining information about the designed puzzle object, and diagnose the cognitive strategies of subjects to find solutions to problems. Designed objects can have different subject contents: graphic, mathematical, verbal, spatial, etc.

1. Introduction
The majority of papers devoted to the study of the learning process use computerized dynamic adaptive tests [1-4]. An essential feature of traditional dynamic adaptive tests is interactivity due to instructive feedback [5]. This leads to the need for computer modeling of the interaction between the intermediary (teacher) and the subject (student). As a result, there is a problem of qualimetry of the learning process. In the context of instructive feedback, the problem of numerical description of the procedural characteristics of educational activities has not yet been fully solved [6].

In this paper, we propose dynamic computer test simulators (DCTS), the interactivity of which is provided by assessment feedback [5], which implies a numerical assessment of the subject's actions, which supports training actions as a reward (+1) for correct actions and as a penalty (-1) for incorrect actions.

DCTS have a closed system for managing the student's activity through negative assessment feedback mechanisms. As shown in figure 1, the DCTS consists of the following subsystems: module of learning material; computation module; control module (adapter); interface of the electronic problem environment (EPE) [7]; activity product recording module.
In figure 1, the following symbols are introduced: $Z$ – external disturbances; $U$ – control actions; $Y$ – controlled quantity (student actions); $R$ – optimality criterion; $F$ – functional; $P$ – control command on the learning material module for the next submission of learning material; $Y_o$ – setting action (task); $X_0$ – control action during the task solution.

The module of learning material is a generator of similar tasks. In each of these modules the subject must collect an object from puzzles with a specific subject content. For example, an object can be a table of English tenses, a sequence of intermediate results of taking certain integrals, or a magic square, etc. Solving one task after another, the subject first gradually detects and eliminates errors in the original understanding of the problem, and secondly, forms connections between various elements necessary for the successful solving the task.

Figure 2. Interface of the electronic problem environment of DCTS.
Interface of the electronic problem environment is shown in figure 2. DCTS allows to organize the educational activity of subjects with puzzles in the electronic problem environment presented with: virtual cards with fragments of the task (puzzles); the viewer puzzles located in randomization stack whose elements (puzzles) can be viewed; a sensor "Distance to target" and its connection to EPE allows to back up the numerical assessment of the validity of the test; the sensor of ten levels of autonomy, determined by the total relative assessment of the accuracy of subject actions; virtual platform on which the subject has to arrange the jigsaw puzzle with fragments of the object. The process of installing puzzles on a virtual platform, and returning them back to the views window (in the stack) is supported by sensor readings. The received external information contributes to human adaptation to the electronic problem environment [7].

The characteristic connection time of the "Distance to target" sensor sets the rhythm of the local feedback loop and is equal in order to the time of the action. The characteristic time of changing the level of independence on the statusogram is equal to the time of solving the problem and sets the rhythm of the main feedback loop. Moreover, the main and local feedback loops are interconnected.

2. Experimental part
Diagnostics of educational activity on the design of objects from puzzles was carried out on a sample of 75 students. The subjects were able to perform three types of actions: 1) viewing puzzles in a special window; 2) installing the selected puzzle on the work field; 3) canceling a wrongly installed puzzle. The subject's activity management system allows to "secretly" monitor and record, in real time, the actions of students when viewing, installing and canceling fragments of the object. Subjects are given the freedom to choose between designing an object in their imagination and constructing it based on visual perception of the actual result. The design of an object from puzzles in the imagination is the result (preference) of the free choice of the subject, so the computer system does not exert any control effects on the actions of "viewing". Moreover, the computer system, recording the actions of "viewing" does not assess them in terms of approaching the goal. During the task solving, hidden logging of actions is performed. The protocols use a binary encoding system (correct actions +1, incorrect actions – 1).

In the process of designing objects from puzzles, with intermediate results of calculating integrals, subjects use three strategies to find solutions. The first strategy is implemented by subjects who can be called observers. Observers have the ability to perform activities internally, i.e. mentally. In figure 3 the actiograms of the actions of the subject - "observer" are presented [8].
The subjects - “observers” design the object in their minds, mentally establishing relationships and identifying connections between the puzzles. In this case, the fragments of the object receive confirmation of the imaginary interpretation, or the subject has a new interpretation from the visual perception of the set puzzles that are part of the whole that unites them.

The second strategy is that students get information about the object from the actual situation. There are almost no actions related to viewing (figure 4).

![Figure 4](image1.png)

**Figure 4.** Actiogram of the subject's actions using the trial and error method.

Their activities are mainly aimed at the installation of the fragments and consequently the abolition, if they thought that the action is wrong. This strategy can be attributed to a trial-and-error approach, rather than an activity based on an external context. This strategy allows the subject to quickly get, even if incorrect, but the image (the actual situation). Since the processing of the actual situation is energetically less expensive than the activity in the “mind”, the subject makes adjustments and corrections and quickly and effectively eliminates erroneous actions.

![Figure 5](image2.png)

**Figure 5.** Audiogram of the student's activity collecting puzzles in a mixed way.
The third strategy is a combination of the first and second strategies (figure 5). In a certain sense, subjects who have the ability to switch from internal activities, the synthesis of an imaginary image in the mind to activities by trial and error based on the external context, are more flexible in terms of organizing educational activities. As you know, manipulating a mental image is always more difficult than transforming a materialized object.

When given a choice, most people will almost always choose to handle the actual situation rather than the imagined one. Therefore, the fact that the subjects from the second group used the trial-and-error way to get information about the object from the actual situation does not mean that they are not able to get information by modeling the puzzle object mentally, in imagination. It rather speaks of their predisposition to “do” first, and then “correct” according to the situation. Moreover, the environment allows to do this. It is surprising that in conditions of freedom of choice, there are people who are quite successful in designing an object mentally, and then implement the results of their imagination in practice. Figure 6 shows a histogram of the distribution of subjects according to their chosen strategies for designing a spatial object. About 50% prefer a mixed strategy, 22% of students try to understand the structure of the object by previewing fragments, and 28% use trial and error way.

The most optimal strategy for designing puzzles corresponds to a mixed mode of activity. In this case, periods of intense puzzle viewing alternate with trial and error, when the subject performs the install and cancel actions. Activity that corresponds to strategy number 3, when subjects first try to design an object in their mind (get some idea), and then proceed to the actual design of puzzles. It requires a significantly greater cognitive resource, a sufficiently developed ability to reflect, a sufficient depth of memory, and a well-developed directed attention. Therefore, the proportion of such subjects is the smallest and is equal to 0.22. The subjects who act by trial and error way refer to the group number 2. If we compare the average number of tasks that were completed by students in groups 1, 2 and 3, then it took 16.3 tasks for the observers, 15.7 tasks for mixed students, and 15 tasks for students working by trial and error way.

The fact that the “observers” had to complete on average more tasks before they excluded erroneous actions is due to the fact that for the subjects, the activity in the mind has a certain complexity and they are much closer and more effective virtual “subject” activity with puzzles, which is implemented by trial and error way.

Figure 6. Histogram of the distribution of students according to strategies for designing a spatial object: group 1 - mixed strategy, group 2 - trial and error strategy, group 3 - strategy of mental activity based on viewing puzzles.
3. Conclusions

From the analysis of the strategies of students' activity in designing objects from puzzles, it can be concluded that if viewing actions predominate, then the subjects, before installing fragments on the work field, try to design the object in their imagination (i.e., implement the first strategy of finding a solution). Such students often go from trying to install to viewing and look through the proposed fragments a lot, trying to understand and determine the structure of the designed image by visual synthesis. We can say that when designing an object from puzzles, the subjects use the method of mental modeling, i.e. the activity is carried out based on the internal context and the imagination of such students is quite well developed.

In the second strategy for finding a solution (see above), the subjects do not try to view the suggested fragments. Their activity meets the strategy of trial and error without modeling the situation in the imagination. The mixed strategy is chosen by the subjects who try to get information about the designed object through viewing fragments, but without achieving the desired result from the use of imagination, switch to the activity through trial and error. With increasing awareness of the object being designed, these students return to viewing fragments.

Iterative solving tasks leads to a change in the structure of the system of actions of the subjects. Regardless of the chosen activity strategy, the subjects can reach a state where each presented fragment (regardless of the order of their change in the viewport) will be associated with a specific cell of the working field. In this case, there is also no viewing of fragments, and the activity will be a continuous installation of the object's puzzles.

The practical significance of diagnostics of cognitive strategies of the subjects' activity in designing objects from puzzles is that it provides information about the features of self-organization of educational activities [9], which allows to get recommendations that improve the efficiency and quality of management of students' educational activities.

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