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Development of a System for Evaluating Cognitive Function of Introducing Ellipses in the Texts of Planimetric Problems

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Abstract. The work is devoted to the study of the cognitive function associated with generating elliptical sentences in the Russian language. This function was tested using an open-source system. The material for testing covers only verbal and nominal ellipses, theoretically fully recoverable on the basis of the context. The texts of planimetric tasks were chosen as testing material. When analyzing the test results, the following facts were revealed: the influence of the respondent's knowledge in the subject area (planimetry) on the understanding of sentences and on the understanding of the syntactic rules for the construction of ellipses; tendency to self-education of respondents; respondents' tendency to remove any parts from sentences that they consider redundant. Thus, the cognitive function of the formation of ellipses has an integrative character and includes a linguistic component (syntax), knowledge of the subject area and mental operations of sentence formation. Due to the revealed complexity of the tested function, the task of evaluating the test results also becomes more complicated. The article is devoted to the consideration of various models for assessing the work of respondents both on an integral basis and in relation to each identified component of the cognitive function.

Key words: online testing system; experiments; cognitive function; ellipsis; planimetry; assessment systems.

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Разработка системы оценки результатов тестирования когнитивной функции при введении эллипсисов в текстах планиметрических задач

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Аннотация. Работа посвящена изучению когнитивной функции, связанной с генерацией эллиптических предложений в русском языке. Тестирование этой функции проводилось с помощью системы с открытым исходным кодом. Материал для тестирования охватывает только глагольные и именные эллипсисы, теоретически полностью восстановимые на основе контекста. В качестве материала тестирования были выбраны тексты планиметрических задач. При анализе результатов тестирования выявлены следующие факты: влияние знаний респондента в предметной области (планиметрии) на понимание предложений и на понимание синтаксических правил конструирования эллипсисов; тенденция к самообучению респондентов; тенденция респондентов удалять из предложений любые фрагменты, которые они считают избыточными. Таким образом, когнитивная функция формирования эллипсисов имеет интегративный характер и включает лингвистическую составляющую (синтаксис), знание предметной области и мыслительные операции формирования предложений. В связи с выявленной сложностью тестируемой функции усложняется и задача оценки результатов тестирования. Статья посвящена рассмотрению различных моделей оценивания работы респондентов как на интегральной основе, так и по отношению к каждой выявленной составляющей когнитивной функции.

Ключевые слова: онлайн система тестирования; эксперименты; когнитивная функция; эллипсис; планиметрия; системы оценивания.

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1. Introduction

Text mining requires automated tools for understanding sentences and their complete syntactic analysis. However, processing texts with ellipses turns out to be a challenging process, as there are currently no faithful methods for ellipsis recovery. Elliptical constructions are those that contain an omitted, but uniquely restored element in sentence (a word or combinations of words) [1]. Ellipsis is a complex and understudied phenomenon in the Russian language, involving the interaction between cognitive knowledge and syntactic rules for sentence construction and parsing. Jefferson was the first who to propose exploring this relationship [2-4]. The study of ellipsis as a cognitive function is the main focus of our work. In the future, this research will lead to the development of automated tools for identifying nominal and verbal groups in sentences, and the resolution of ellipses on this basis [5] – a task that has not yet been solved.

In our work, to study the cognitive function of ellipsis formation, we selected the field related to the texts of school tasks on planimetry. The class of ellipses was also chosen with some restrictions: we limited only to verbal ellipses and nominal ellipses with the preservation of a representative [5],

which theoretically allow full resolution. Let us recall some rules for generating sentences with verbal and/or nominal ellipses [6].

- *Rule 1*. If an action over (with) several objects is meant, then after the description of this action over (with) the first object in a sentence, further this action over (with) other objects can be described without copying the name of this action (the verb is skipped);
- *Rule 2*. A verb can be included in a sentence as part of a verb phrase (VPh), then, after a complete description of the action on the first object, it is possible to omit not only the verb, but also the repeated components of the verbal actants in subsequent descriptions of the same action on other objects;
- *Rule 3*. An object can be expressed as a part of nominal phrase (NP), then when the same object is mentioned in a sentence, it is possible to omit not only its name, but also the common (repeated) components of the NP that characterize the object;
- *Rule 4*. If the designation of an object is introduced in a sentence, then further in this sentence it can be used only this designation without the name of object.

When creating a system for testing cognitive function asso- ciated with selected types of ellipses, we sought to find out:

- how much this function is related to learning;
- how does it interact with knowledge about the subject area;
- what are the most likely and adequate domain knowledge models that support this feature;
- what cognitive and syntactic rules ensure the existence of this mental function.

The creation of a testing system also has several applied goals, one of them is the early detection of dementia. The cognitive function of generating or restoring an ellipsis of the selected type just requires testing short-term memory to memorize the preceding part of a sentence without an ellipsis. In this case, only one sentence is required.

The first experiments on testing the system have already shown the need for expanding the system in the following areas:

- creation of a database with proposals containing ellipses on this subject and its integration with Russian-language databases (for example, The National Corpus of the Russian Language [7], Taiga Corpus [8]);
- automation of the process of preparing sentences for testing, including the selection of sentences from databases and the conversion of elliptical sentences to complete and vice versa (conversion of complete sentence to elliptical, possibly by machine learning methods).

Before proceeding with the functional expansion of the testing system and the global analysis of automatic ellipsis processing methods, it is necessary to establish standards for evaluating the work of respondents when they introduce ellipses into a sentence. It turned out to be a difficult task.

2. Process of testing

The task (question) during testing is to transform the sentence given in the question without an ellipsis into an elliptic one using the examples of sentence transformation with verb and nominal ellipses shown to the respondents in some educational part. The test contains 10 such tasks. Example of a task:

> "The sentence for transforming it (without violating the meaning of this sentence) in an elliptical one is:
>
> In an isosceles right triangle ABC with its right angle at vertex B, a rectangle MNKB is inscribed so that its two sides MB and KB lie on the legs, and the vertex N lies on the

hypotenuse AC.

click on repeated words to cross them out".

A detailed description of the testing system is given in the work [9].

3. Analysis of the results of the pilot study

At the moment, two testing sessions have been held. The respondents were students of technical specialties of Peter the Great St. Petersburg Polytechnic University (SPbPU). There was no special selection of respondents according to any criteria, because when studying cognitive functions, it was interesting for us to cover different groups of respondents and only then, perhaps, to consider the correlation of results with academic performance The first session was held in May 2023 and the second in December 2023.

In order to remove anomalous divergences in the dispersion diagrams of various indicators, the following filter was applied: the total time of 10 answers greater than 1200 seconds, at least

6 questions were answered in total. According to the combined data set, 99 respondents took part in the test, 21 were filtered, and 78 remained.

The average time to complete the test is 11 minutes. The average score of respondents is 6.76 out of 10 possible (10 tasks). In addition to the scores, qualitative assessments of the test results were introduced: "True" (T), "False" (F), "Partially Correct" (PC) and "No Answer" (NA).

Estimation "T" was given if the respondent's set of crossed- out words fully coincided with the words that should be crossed out in the correct answer. Estimation "PC" was given if there was only a partial match with the words crossed out in the correct answer. Estimation "F" was given if no words were crossed out of words in the correct answer. The disadvantage of such an assessment was that estimation "PC" could be obtained if the verb was not crossed out – but, with the VPs, this answer is incorrect.

The listed estimations did not depend on whether or not the respondent crossed out some words not contained in the correct answer.

A detailed analysis of the results of the first testing session is given in [10, 11].

Let us dwell on those sentences in which the respondents' mistakes were not related to the syntax of the ellipsis, but to the violation of the meaning of sentences.

In sentence 1 the respondent crossed out the second appearance of "the median perpendicular" in the sentence. In this case, the respondent allows simple deletion of the repeated fragment of text with the violation of the meaning of sentence.

Sentence 1: On the side BC of triangle ABC, point A* is taken; the median perpendicular to line segment A*B intersects side AB at point M, and the median perpendicular to line segment A*C intersects side AC at point N.

In sentence 2 the respondent crossed out the second appearance of "circumscribed circle". Here, again, it is impossible to delete the repeated fragment, since geometrically we are talking about the circumscribed circle of another triangle.

Sentence 2: These equations mean that OB touches the circumscribed circle of triangle ABM, and OD touches the circumscribed circle of triangle ADM.

In sentence 3 the prohibited crossing out is to cross out the repeated word "singular".

Sentence 3: A circle touches sides AB and AD of rectangle ABCD and intersects side DC at the singular point F, and side BC intersects at the singular point E.

In these sentences, the respondents deleted the words uniquely determining the heads of NPs. However, in elliptical sentences, there are omitted the pivotal words (the heads of phrases, for example, the heads of Noun and Verb Phrases), but their subordinate (dependent) words remain [12]; Additionally, the repeated fragments are included in the NPs related to different planimetric objects requesting unique characterizations. Thus, the relationship of ellipsis generating not only with the syntactic structure of a sentence, but also with the subject area (in this case, planimetry) is

revealed. And this is an important result, since it resolves experimentally the dispute between representatives of two approaches of Western linguistics to the resolution of ellipses: generative and cognitive linguistics [13]. Adherents of the generative linguistics believe that the meaning of ellipsis is determined only by its antecedent and consider it to be only a syntactic unit [14]. In the cognitive approach, it is argued that the meaning of missing part is closely related to the meaning of the entire sentence. Understanding the sentence entails understanding the ellipsis. The meaning of the ellipsis is determined both by the explicit part of the sentence and by the knowledge of the subject area, including context, linguistic, pragmatic, and encyclopedic knowledge, etc.

Analysis of the test results showed that respondents often associate ellipticity with getting rid of any redundancy in the text. However, they correctly use both the cognitive rules presented in [6] and the knowledge from the field of planimetry. For example, in the sentence 3 a respondent crossed out the word "side", since the designation BC, taking into account the previous part of the sentence, says that BC is the side of rectangle (Rule 4).

Now, in each sentence, there are many words not related to the ellipsis, but these words can be crossed out. The analysis of such permissible deletions makes it possible to study in more detail the cognitive methods of reducing redundancy in texts.

For example, 5 respondents crossed out the repeated words "straight lines" in sentence 4.

Sentence 4: A straight-line parallel AB crosses AC and BC at points M and N, and straight-lines parallel AC and BC cross AB at points P and Q.

16 people crossed out the word "two" in the combination "two others" in sentence 5.

Sentence 5: A circle of radius R and a tangent to it are given; construct a square so that its two adjacent vertices lie on the tangent, and the other two lie on a circle.

Such crossing-out can be divided into two groups:

- *Group 1*. These are deletions, in which the knowledge of the subject area – planimetry – is used;
- *Group 2*. Deletions related to the understanding of the process of text generation, to the memorization of the previous text, that is, to the understanding of the sentence.

4. Development of systems for evaluating the results of entering ellipses in planimetric texts

4.1 Possible assessment systems

The original system of evaluating with the use of the plugin of "Striking" had the following logic: all possible words are found, the exclusion of which will make an elliptical sentence from the complete one. Each word is assigned a share of the maximum score (100%), the shares for each word are equal. If only one word can be crossed out, its share is 100%. The respondent's answer is checked for each correctly deleted word, the share of this word is added to the final score. Thus, if 3 words out of 4 possible ones are crossed out, the student receives 75% of the maximum score. Next, we will call this system of assessment SoA-0, since it is a pilot, such testing has not been carried out before, so the concept of the "correct" answer needed to be developed.

SoA-0 has a number of drawbacks, and the first drawback is the evaluation of crossing-out as "partially true", when it actually violates the style of the sentence. For example, for question number 2: "A cube is inscribed in a regular quadrangular pyramid so that four its vertices belong to the lateral edges of the pyramid, and the remaining four its vertices belong to the plane of its base". There are several correct (not violating the structure and style of the sentence) options for crossing out words to create an ellipsis (in Russian sentence, we have more options):

- A cube is inscribed in a regular quadrangular pyramid so that four of its vertices belong to the lateral edges of the pyramid, and the remaining four of its vertices **belong** to the plane of its base.

- A cube is inscribed in a regular quadrangular pyramid so that four of its vertices belong to the lateral edges of the pyramid, and the remaining four **of its** vertices **belong** to the plane of its base.
- A cube is inscribed in a regular quadrangular pyramid so that four of its vertices belong to the lateral edges of the pyramid, and the remaining **four of its** vertices **belong** to the plane of its base.

The second drawback is that it is not possible to assign a penalty for the crossing-outs that violate the meaning of the sentence from the point of view of geometric objects. The third disadvantage of SoA-0 is the impossibility of analyzing statistics by means of Moodle Quiz, since in order to process answers in the Moodle system, it is necessary that at least 1 answer is evaluated at 100%. Based on the above disadvantages of SoA-0, there is a need to develop a new assessment system for a Moodle quiz question type plugin "Striking". Let's consider several assessment systems.

1) SoA-1: Naive assessment. Estimation true/false (1/0) for understanding ellipticity is assigned when the respondent has crossed out a verb and additionally some repeated words of VPh. If there is a violation of the meaning of the sentence, the respondent is notified in addition to the ellipsis understanding score when displaying the test results.
2) SoA-2: Assessment with permitted set of words. The allowed set of words will be considered not an empty list of words that can be crossed out without losing the meaning of sentence. So, for the above question number 2, there are 5 correct sets (in Russian). Words included in the allowed sets form a list of "correct" words. However, not all combinations of "correct" words allow you to get a stylistically correct sentence after their removal.

   That is why it is more logical not just to check the presence of each word crossed out by respondent in the list of "correct" words, but to compare the entire set of crossed out words with the "correct" subsets of this list. In addition to the list of "correct" words, a list of "forbidden" words is also formed, the crossing out of which violates the meaning of the sentence. If the respondent's answer contains at least one word from this list, he is given score equal to 0, even if the other words are in the correct set from the point of view of ellipsis.

   The respondent is also notified of a penalty for violation of the meaning of sentence.
3) SoA-3: Assessment similar SoA-2 with an additional set of words to be crossed out. The logic of this system repeats SoA-2. In addition, for each sentence, a list of "acceptable" words is formed, which can be crossed out to avoid redundancy, but their deletion does not entail the appearance of a "gap" in the syntactic structure of sentence as opposed to the syntactic structure of an elliptic sentence.

   According to this system, the words crossed out by respondents are divided into 4 categories: those included in the lists of "correct", "prohibited", "acceptable" and "other" words. If the number of "forbidden" and "other" words in the respondent's answer is zero, the set of words included in the list of "correct" words is checked for compliance with the "correct" subsets and the correct (1)/incorrect (0) score is given based on the results of the check. If the respondent's answer contains words belonging to the "prohibited" and "other" categories of words, the score is incorrect (0). This entails explaining to the respondent the reason for assessing his answer as incorrect.

4.2 Quality indicators of test tasks

In the Moodle learning management system (LMS) there are parameters for assessing questions not calculated in the pilot version but have been implemented in the current version of the system.

For each question, there are the following indicators [15]:

1) The facility index shows the part of respondents answering correctly to the analyzed question. If the permissible score for the task is zero (incorrect) or one (correct), then the

facility index (solvability coefficient) is the ratio of the number of respondents answered correctly to the total number of those who answered this question. It is better to exclude questions with the facility index of more than 0.9 and less than 0.1 [16]. The facility index will be further denoted by Fp.

2) Standard Deviation (SDp) characterizes the spread of the values of the scores received for a question. If this indicator is zero for the question, it means that all test takers received the same score for it. Such a question should be recognized as unsuccessful. In accordance with the requirements of the pedagogical theory of measurements, it is better to exclude tasks with the SDp value less than 0.3 from the test, because they do not have sufficient differentiating ability, i.e., they are not able to separate strong and weak respondents.
3) The discrimination index (Dp) shows the interrelation between the correctness of answer to a question and the correctness of answers to the rest of the test questions.

   At the same time, it is noted that if the index Fp of question is different from 50%, then the index Dp cannot be 100%. If the Fp index is close to zero or 100%, then the Dp index will always be very small, and if the Fp index is equal to zero or 100%, the Dp index will not be determined.
4) Discriminative efficiency (DEp) is an indicator that is largely similar to the Dp index, but does not have the disadvantage mentioned above (the value of Dp may not be determined in some situations). Based on this fact, it was decided to consider only the DEp for each question. A question is considered to have sufficient differentiable capacity if the DEp index is greater than or equal to 30%.
5) Intended question weight is the weight that is assigned to the test when the test scenario is generated.
6) Effective weight characterizes the actual share of a particular task in the final score of respondents for the test.

4.3 Analysis of indicators in different SoA

Using the python programming language tools and formulas presented on the official moodle website, we found the values of the above coefficients. Table 1 shows the values of Fp, SDp and DEp for each question in different SoA. The intended weight for each question is 10%, since the maximum score equal 1 can be obtained for each question, and the total of score equal to 10 can be obtained for the test.

Table 1. Indicators of each question in different system of assessment (SoA).

	SoA-1				SoA-2				SoA-3		
	Fp	SDp	DEp, %		Fp	SDp	DEp, %		Fp	SDp	DEp, %
2	0.68	0.47	66.5		0.66	0.48	69.2		0.6	0.49	66.7
3	0.81	0.39	75.5		0.81	0.39	77.8		0.75	0.44	72.1
4	0.51	0.5	78.2		0.38	0.49	72.5		0.31	0.46	75.9
5	0.74	0.44	67.4		0.53	0.5	41.9		0.51	0.5	50.4
6	0.41	0.49	62.7		0.41	0.49	61.9		0.34	0.48	57.1
7	0.73	0.45	69.6		0.73	0.45	70.9		0.61	0.49	71.8
8	0.84	0.37	68.5		0.84	0.37	69.6		0.76	0.43	71.7
9	0.79	0.41	69.8		0.49	0.5	51.2		0.49	0.5	57.2
10	0.66	0.48	51.7		0.66	0.48	40.8		0.4	0.49	68.0
11	0.46	0.5	41.6		0.45	0.5	38.5		0.43	0.49	44.3

Depending on the SoA used, the values of the indicators change slightly, this fact may indicate the nature of the questions: for example, question number 11 in all SoA has relatively low Fp and DEp, these low values can characterize the question as difficult.

A low DEp of a question tells us that a certain group of "strong respondents" made mistakes in this question on a par with weak ones. Also, question number 6 in all SoA has the lowest solvability rate (value of Fp) and average (relative to other questions) value of DEp. Strong respondents coped with this question better than weak ones, compared to question 11, but the lowest The Fp index tells us that a large number of weak and average respondents did not solve this question.

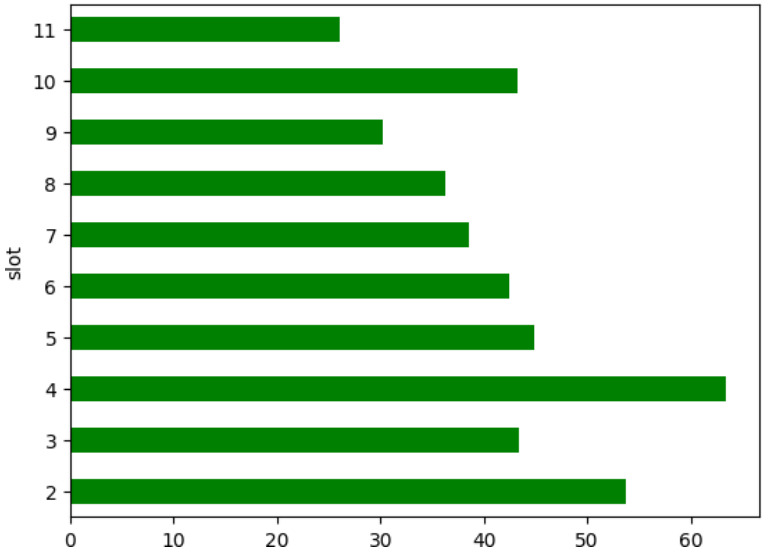

Fig. 1. Average time for each question.

One of the easiest questions is one with the number 3, it has the highest value of the Fp index. In addition to the highest value of the Fp index, it also has one of the highest values of the DEp index, this fact means that strong respondents coped with it much better than weak ones, most likely it was the weak respondents who made mistakes in this matter. Let's compare the complexity of the questions with the time spent on. A graph of the distribution of the average time for answering each question is given in Fig. 1.

Question number 4 is highlighted on the graph. Let's consider its indicators. According to the Fp index for SoA-1, half of the test participants solved the question, while it has the highest the DEp index, this fact may mean that it was mainly the strong half of respondents who coped with it. In SoA-2 and SoA-3, the Fp index of question 4 becomes the lowest one compared to the rest of questions. Recall that SoA-2 and SoA-3 imply penalties for violating the meaning of sentence. Just for this question, we have defined a set of "forbidden" words that cannot be crossed out. And it was these words that were crossed out by 19 people out of 78. It can be noted that a large amount of time spent on this question was not confirmed by high ratings. This question can be considered really difficult. The second observed high value of the average time spent was found in question with number 10. Judging by the Fp index in SoA-3, it can be concluded that quite a lot of respondents crossed out "extra" words.

The solution of the most difficult question with number 11, according to the indicators, took the least time. Perhaps it was because of the short thinking time that many respondents did not cope with the task. In addition, there is a possibility of a decrease in motivation by the end of testing.

What could be other reasons for the difficulty of question 4? The text of this question is given in sentence 6.

Sentence 6: On the side BC of triangle ABC, point A* is taken; the median perpendicular to line segment A*B inter- sects side AB at point M, and the median perpendicular to line segment A*C intersects side AC at point N.

Firstly, when reading, the respondents seem to "stumble" the designation *. Secondly, the concept of "median perpendicular" is quite difficult to imagine.

Let us consider question 10 in detail (sentence 7). A complex sentence structure consisting of repeated parts, so the respondents probably had to reread it several times to realize which shape touches the other and at what point. We can conclude that in order to search for redundancy, the respondents actually delved into the essence of the geometric problem, perhaps mentally imagining the described figures.

Sentence 7: 3 points A, B and C are given on the plane; construct three circles k1, k2 and k3 so that the circles k2 and k3 touch each other at point A, the circles k3 and k1 touch each other at point B, and the circles k1 and k2 touch each other at point C.

Another interesting task is the task with number 2 (sentence 8). In this text, the respondents deal with a three-dimensional figure and they try to visualize the configuration mentally. Also, the increase in the time spent working on this question can be explained by the fact that this is the first task of this type in the test.

Sentence 8: A cube is inscribed in a regular quadrangular pyramid so that four its vertices belong to the lateral edges of the pyramid, and the remaining four its vertices belong to the plane of its base.

5. Conclusion

The paper analyzes the results of two sessions of the experiment. The average score and the average time of passing the test were found.

The crossing-out that are often found among the respondents' answers are analyzed separately. As a result, it was established that the correct understanding of the ellipsis depends on the understanding of the entire sentence and knowledge of the subject area.

Three approaches to the assessment of testing in LMS Moodle are proposed, which involve assigning a score without taking into account the deletions that violate the meaning of sentences, as well as taking into account such deletions by assigning a penalty in the form of zeroing the estimation. The introduction of new estimation systems made it possible to calculate the performance indicators of questions given in LMS Moodle. Based on the values of the facility index and the discriminative efficiency, the authors were able to conclude about the difficulty and ease of the test questions.

An important indicator of the difficulty of question can be considered the time spent on it. When trying to compare the difficulty of question with the time spent on it, the following trend was noted: a large amount of time was taken up by questions containing geometric concepts or sentences with a complex structure that are difficult to mentally reproducing.

As a further development of the testing system, the authors plan implementing the most optimal assessment system in the question plugin, as well as adding the ability to create a "training" question, the answer to which can be seen during the test, so that respondents have the opportunity to try out the elimination functionality and, possibly, better understand the essence of testing. In addition, the authors intend to explore methods for generating elliptical sentences for the development of the task bank.

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