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EMS2016-2168

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This paper should be cited as follows:

Orozco Vaca, L.G, (2016). **"Self-instructions for Applying Writing as a Metacognitive Tool in Problem Resolution",** Athens: ATINER'S Conference Paper Series, No: **EMS2016-2168.**

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Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
URL Conference Papers Series: www.atiner.gr/papers.htm
Printed in Athens, Greece by the Athens Institute for Education and Research.
ISSN: 2241-2891
28/03/2017

Self-instructions for Applying Writing as a Metacognitive Tool in Problem Resolution

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Abstract

This article describes the results of a teaching experiment, whose purpose is to support secondary school students (9th grade) in solving geometry problems by using writing as a metacognitive tool throughout the process. We claim that writing can encourage a process of analysis in mathematical concepts and work techniques. We designed self-instructions that were presented to students in the form of simple questions, through which the students exercise writing as a metacognitive tool in solving geometry problems, for the purpose of organizing and overseeing the elements that take part in the activity process.

Keywords: Self-instructions - Questions - Writing - Problem resolution

Introduction

Throughout my professional experience as a teacher, I have seen poor comprehension of mathematical concepts and procedures by students, as well as unorganized problem resolution strategies. This lack of organization is shown when students start solving a problem before clearly distinguishing the information, the procedures and the reasoning developed in order to arrive at the answer. Likewise, their notes are disorganized and devoid of a systematic nature.

This paper explores whether systematized writing can be a tool that facilitates problem resolution. To that end, we designed a teaching experiment that proposes the use of writing strategies as an organizer in the elements involved in the various phases of an activity cycle for solving geometry problems in the third year of secondary school, guiding students by a way of self-instructions to make conjectures and reflections throughout the process of the activities.

Theoretical Framework

The metacognitive skills are described by Veenman (2012) as the regulation of cognitive processes, that is, the acquired capacity for oversight, orientation, direction and control of proper behavior in learning and problem resolution. Veenman (2012, 2011, 2005) makes a distinction on which activities he considers to be representative of metacognitive skills. He separates them into three categories, as we can see in Table 1.

Table 1. *Metacognitive Skills*

Learning Activities		
At the beginning of task execution	In the process of task execution	After task execution
− Reading − Analysis of the assignment of tasks − Activation of prior knowledge − Setting goals − Planning	− Following a plan − Changing the plan − Follow up − Control − Note taking − Time and resource management	− Performance assessment − Recapitulating − Reflecting on the learning process

These metacognitive skills present a recurrent difficulty that is shown when higher order activities are described to a significant extent in terms of lower order cognitive processes. For instance, a reading and reasoning process is required in the analysis of a task assignment; note taking follows the line of writing; evaluation and reflection implying making comparisons, which are metacognitive skills. Metacognitive skills themselves constitute the direction while cognitive processes integrate the medium for the skills to be employed.

In order to more clearly explain the situation of cognitive and metacognitive activities involved in a task, Veenman compares cognitive activities with soldiers and metacognitive self-instructions with the general. Explaining that a general can't win a war without soldiers, but on the other hand, an entire army that is unorganized will not be successful. Metacognitive instructions *per se* are always managing cognitive activities, and the proposed task can't be achieved without this oversight. He also confirms that metacognitive skills are fine-tuned mainly through four types of learning processes: reading text, solving problems, learning by discovering and writing.

Hyde (2006, 1991) is guided by cognitive psychology principles and uses the term braiding to mean that the language, thought and mathematics can be interlinked into a single entity, leading to a stronger, more durable and powerful result when these three important processes are connected than if each of them were working independently. The term braiding suggests that the three components are inseparable, provide mutual support and are necessary. He asserts that to the extent a connection between related ideas is strong; the comprehension of a concept is deep and rich.

We reviewed the work of Veenman (2012, 2011 y 2005), which distinguishes between metacognitive knowledge and metacognitive skills, in order to guide their development in teaching science. We also reviewed the research of Hyde (2006, 1991), who applies the Braiding Model in primary education to solving mathematics problems. We then took some of the useful elements of the work of both into account in designing our teaching experiment, which consists of using writing as a metacognitive tool in solving geometry problems, as the following section describes in detail.

Methodology

The interest of this research is to work with 10 9th grade students on the use of self-instruction in problem resolution through written productions in order to ascertain, on the one hand, what they are thinking and, on the other, to mobilize the function of writing as a metacognitive tool.

Design of the Teaching Experiment

On the basis of the list of self-instructions that Veenman (2012) proposes for regulating tasks, together with Hyde's (2006) Braiding Model for combining language, thought and mathematics, our interest arose in exploring experimentation that the students can apply for themselves, without needing total support from the teacher. On that basis and providing very simple albeit useful direction, students arrive at the solution.

Therefore, our teaching experiment consists of supporting students in solving geometry problems, for which we establish a five-phase plan, as follows: 1. Make explicit the concepts involved in the problem, as well as the given information and the information sought. 2. Use manipulative objects that help clarify the information 3. Develop picture representations (drawings, diagrams or graphs). 4. Develop symbolic representations (change to mathematical language). 5. Write down the solution to the problem and justification of the answer. In order to move through each of the phases, the students are guided by simple questions that lead them to obtain the solution; indeed, a list of self-instructions for regulating the process.

Self-instructions for Using Writing as a Metacognitive Tool in Problem Resolution

Self-instructions nominated in this experiment first focus on the writing of information provided in the problem, in order to clarify what we know and what is understood in the problem. Then the writing of what is vague, that must be delved into. Followed by the writing of what needs to be ascertained and subsequently of where that will lead. Finally, the student must justify in writing the results obtained and the proof that it is in fact the solution to the problem.

Self-instructions are designed as simple questions for students, so they work through the learning activities needed for development of their metacognitive skills during the problem resolution process. Each question is focused on a learning activity, as described in Table 2, and employs writing as a metacognitive tool throughout the process.

This research is primarily qualitative in nature, using the line method for assessing metacognitive skills (Veenman 2012) through the written compilation of the entire process followed by the students in solving the problem. All notes made by the students on the worksheets facilitate our analysis of the expressions in the process, in addition to considering the influence of context throughout development of the solution of each problem.

Table 2. *Link between Self-instructions and Veenman's Metacognitive Skills*

Self-instructions designed for using writing as a Metacognitive Tool in problem resolution		**TASK**	**Learning Activities representative of Metacognitive Skills**
1	What information am I given in the problem?	START	Reading
2	What do I need to find?		Analysis of the task
3	What knowledge do I have about the topic?		Activation of prior knowledge
4	How am I going to solve it?		Planning
5	What steps will I follow?	DURING	Follow or change the plan
6	What drawings could help me arrive at the solution?		Note taking
7	How do I justify the answer I found?	AFTER	Performance assessment
8	Is this the only way of arriving at the answer?		Recapitulate
9	What other forms can you apply?		Reflection on the process

Results

This section examines the abilities that the students applied in problem resolution, noting that metacognitive skills are made explicit by encompassing four categories in the activities -direction, planning, follow up and assessment- which are acquired with representative activities described by Veenman (2012). Therefore, the results will be interpreted by a way of metacognitive skills that occur during the resolution of a problem, as shown in Table 2.

Activities at the Beginning of Problem Resolution

The activities at the beginning -reading, analysis of the tasks, activation of previous knowledge and planning- prepare a student for solving each problem and, in some cases, they are interlinked. That is, one activity drives the other.

Reading and Analysis of the Problem

Reading and analysis of the task were demonstrated via two different activities when starting to solve the problem. The first was a description and correct interpretation of the problem information (Figure 1) and the second were the statements supporting comprehension of the problem information (Figure 2).

Figure 1 shows the answer of a Student A, who collects and deploys the information provided in the problem, as well as the information he seeks in a concise manner. He uses the support of annotations of equality to establish the relationship between the areas of two different polygons "CFDG = At EFGH÷ 3". This statement demonstrates that it is clear to him that the area of the polygon is equal to one third of the area of the EFGH square, and that is the reason he establishes the equality based on the symbology of the points that make up each polygon.

Figure 2 shows the answer of another student, Student B who, in addition to recovering and concisely displaying the information provided in the problem and the information that must be found, uses the support of his understanding of the information "the measurements of the square are 6 cm per side and AB are the midpoints of its sides and the area of CFDH is one third of the area of the square". Moreover, the answer to the second prompt coincides with the information sought, "the length of CD" as in Figure 1.

The first part of each figure shows how metacognitive skills are activated from the first two keywords, particularly the activation of reading comprehension and interpretation of information based on reading, as well as the use of drawings as representations, which will be helpful throughout the process of solving the problem. Likewise, in some cases part of their prior knowledge is activated, knowledge that has not yet been added to the prompts, but they do it automatically with the reading and analysis of the problem.

Activation of Prior Knowledge

The metacognitive skills identified through the third self-instruction is the activation of prior knowledge, driven by the memory processes of each student, which are activated when relationships are established between the information provided by the problem, what they seek to find as an answer and knowledge of topics considered necessary in order to obtain the solution to the problem. Indeed it is a process of remembering information stored in their minds, relating it to the information they are working with and deciding on which process to apply in order to obtain a solution.

The activities that showed activation of prior knowledge were the description and assertion of the concepts in topics related to the problem and the use of formulas together with symbolic writing. As Figures 1 and 2 demonstrate, the students A and B use statements or assertions with simple expressions “I know getting the area...”, “I know how to get the area...” with which they describe knowledge about the topic to be worked on in the problem.

Planning

Planning the task is the last activity of the beginning of a task. It implies that the students prepare the process of organizing the steps to be followed in order to reach the answers. First, the steps are performed and then the objective is reached. In fact, the organization of the path to be followed together with a specific order, which the student must follow in order to solve the problem, is indicative of their planned behavior.

Figure 1. *Answer from Student A Participating in the Teaching Experiment*

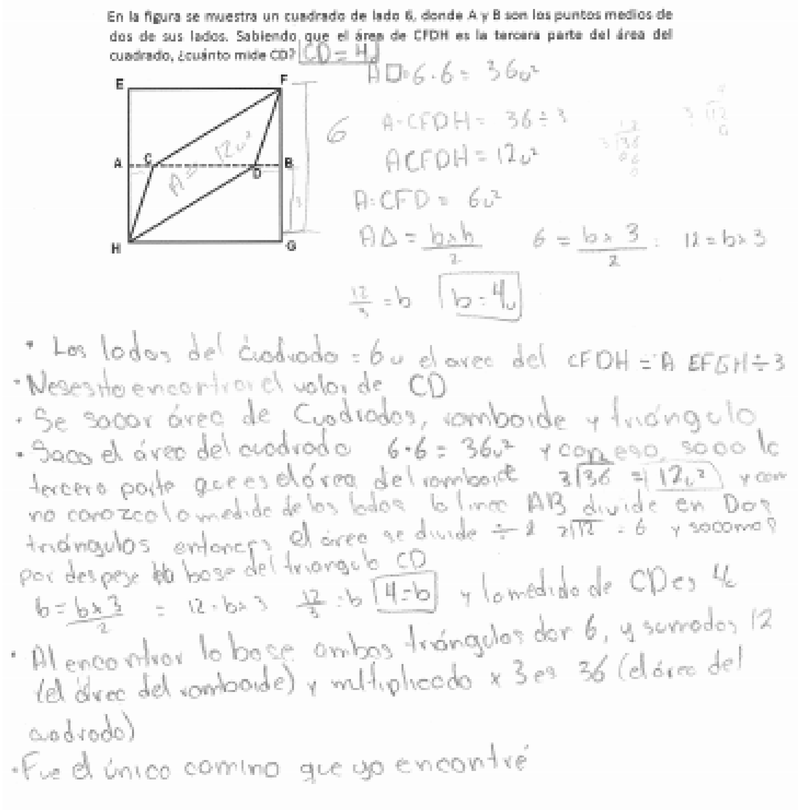
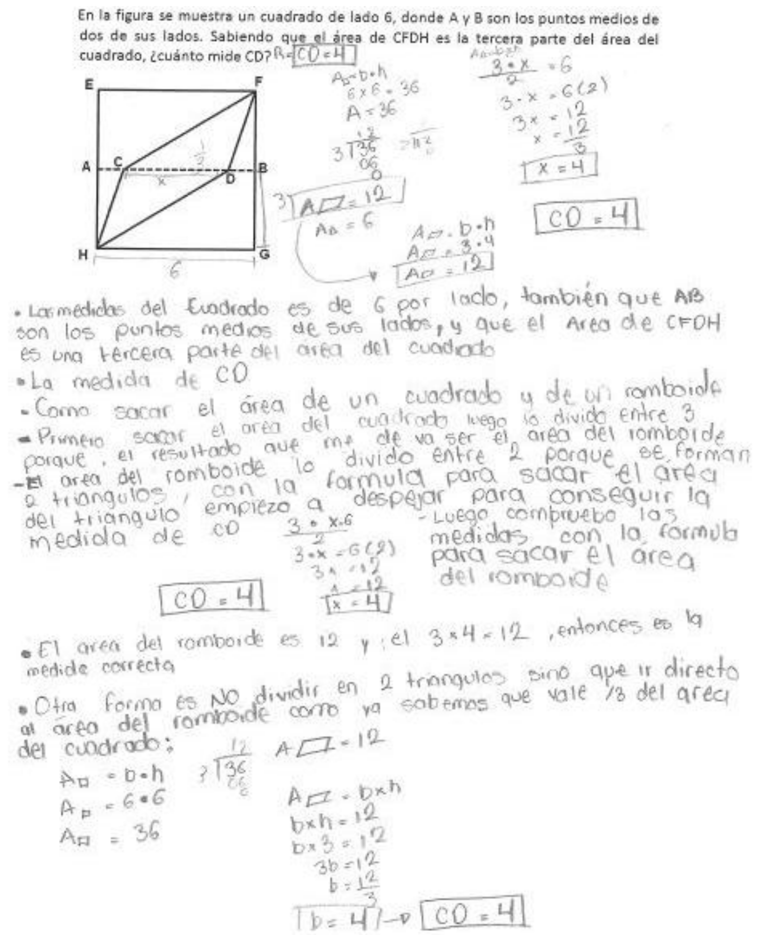
Question 6 Question 1 Question 2 Question 3 Question 4 Question 5 Question 7 Question 8	
	· The sides of the square = 6 u the area of CFDH = A EFGH ÷ 3 · I need to find the value of the CD · I know how to get the area of squares, rhomboids and triangles · I get the area of the square 6· 6 = 36 u^2 and use that to get one third of it, which is the area of the rhomboid 12 3 ⌈ 36 = 12 u^2 and since I don't know the length of the sides, line AB divides it into two triangles so the area is divided ÷ 2, 2 ⌈12 = 6 and we isolate the base of the triangle CD. · The length of CD is 4u. · When we find the base of both triangles we have 6, and adding them is 12 (the area of the rhomboid) and multiply x 3 is 36 (the area of the square) · It was the only way I found.

Figure 2. *Answer from Student B Participating in the Teaching Experiment*

Question 6 Question 1 Question 2 Question 3 Question 4 Question 5 Question 7 Question 8 Question 9	
	· The measurements of the square are 6 cm per side and AB are the midpoints of its sides and the area of CFDH is one third of the area of the square · The length of the CD · How to get the area of a square and a rhomboid · First get the area of the square and then divide it by 3 because the result I will get is the area of the rhomboid · The area of the rhomboid I divide by 2 because it makes 2 triangles, with the formula to get the area of a triangle I work it out until I get the length of CD · Then I check the lengths with the formula for getting the area of a rhomboid · The area of the rhomboid is 12 and 3 x 4 = 12, so the length is correct · Another way is to NOT to divide into 2 triangles but directly get the area of the rhomboid which we know is 1/3 of the area of the square:

When working through the planning of a task, the students demonstrated the decision and order of the steps to be followed together with the assertions concerning the procedure to be applied in solving the problem. Figure 2

shows how the Student B made the clearest choice for the steps to be followed in his planning, where he says: “First get the area... then I divide by 3 because the result I will get will be the area of the rhomboid”, establishing the two first steps, showing how the information given in the problem was clear and he was able to establish the relationship with the shapes.

He continues saying “I divide he area of the rhomboid by 2 because it makes 2 triangles, using the formula to get the area of a triangle, I work it out until I get the length of the CD”, we see that he identifies the properties of the figure and asserts the formation of 2 triangles that have the same base and height, which is why he decides to use the formula to obtain the area of the triangle and correctly solve the problem. In Figure 1, the Student A decides to formulate assertions when explaining how he will proceed in order to solve the problem. This narrative allows us to see how he has correctly identified the information that A and B are the midpoints and clearly distinguishes the shapes that are formed within the rhomboid.

The first four self-instructions show how the metacognitive skills of orientation is satisfied, which Veenman addresses, reading the wording of the problem, the activation of prior knowledge as well as the specification of what is given and what is sought. The student’s work also shows evidence of use of the metacognitive skills of planning, as it shows how they outline a procedure they can follow, which is organized in a specific order, as well as the correct path for arriving to the answer. Other components of planning are revealed in the activities that occur during problem resolution, which we shall see in the next section.

Activities during Problem Resolution

The activities during execution of the task are: following the plan, changing the plan if necessary, taking notes and resource management (Veenman 2012). All these activities guide the students during problem resolution and control the performance of the task. The indicators for metacognitive skills during the execution of the tasks are seen by the way the students follow up the plans of action they designed at the start, performing each of the necessary activities step by step in order to solve the problem.

The follow up processes observed in the following two sections show how students used metacognitive control and note taking processes in problem resolution, in terms of the two activities -following the plan and note taking- and using the “what steps will I follow?” and “what drawings will help me reach a solution?” self-instructions as a guide.

Carrying out the Planning

The first question leads the students to carry out the planning designed in the previous prompt, start-making deductions, progressing through the process and correcting any errors that may have been made. A student following the plan developed with the self-instruction above states how the metacognitive processes are the step-by-step action of the plan grouped together with the verification of the results through numeric processes.

In Figure 1, the Student A writes out the operations together with the narrative of the process, reflecting how each step is correct and guiding him to the next step in order to finally arrive at the length of the segment CD. Whereas in Figure 2, the Student B describe their procedure based on the information of the geometric representation of the problem, which together the corresponding operations and the correct order leads to the correct answer.

We see how these responses express the convincement the students have both of their geometric interpretation of the figures, and the arithmetic calculations used to arrive to the answer. Some students also combined the algebraic representations to later apply the operations. They all demonstrate confidence and control of the steps to be followed in reaching the correct answer, as we have seen in the worksheets.

Note Taking

Note taking is a metacognitive process that depends on cognitive processes like writing and the representations made by students during the execution of a task. Notes extend the description of the development of the steps to be followed in solving the problem (Veenman 2012). In this research, we focus on notes written by students outside of the narrative process, starting with notes made in the representation given of the problem, followed by representations they add to each description according to the prompt -What drawings could help me arrive to the solution? In addition, taken into account were notes on formulas and operations used to arrive at the result, which we did not expect to find, but which provided an opportunity for analysis (indicated in Question 6 of Figure 1 and Figure 2).

We identify how most students started by using the representation given for each problem, which helped guide them through following the process. When they were insufficient, the students developed other representations that could clarify the problem situation and added information they considered necessary. They then proceeded to verify that their procedure was indeed correct.

As we can see in Figure 2, the Student B writes the fraction $\frac{1}{3}$ inside rhomboid CFDH to indicate that the area of this figure is one third of the area of the square, in addition to marking segment CD with an *x*. The student then starts working out the area of the square, followed by the area of the rhomboid, which is one third of the square, and based on the answer the student identifies that there are two identical triangles. He then proceeds to work with the formula for the area of a triangle to obtain the length of the segment of the CD; on the other hand in Figure 1 the Student A writes down $A=12u^2$ inside the rhomboid, which represents one third of the area of the rectangle and then applies a similar process.

In these descriptions, we see that with note taking, drawings made by the students and the representations given in each problem, together with notes of formulas and operations, together direct and control the entire process applied in solving each problem.

The conditional part of working on writing and following self-instructions has generated certain actions from the students, such as the description of the steps used to obtain the answer and the orderly representation, which allows them to monitor and reflect on their processes. These activities facilitate acquisition of skills, where a metacognitive strategy must be applied consciously, step by step, to be then gradually transformed into a skills based on a follow up process. Students review and recapitulate their work after solving the problem in the next section.

Activities after Problem Resolution

The last three questions posed are: How do I justify the answer I found? Is this the only way of arriving at the answer?" and "What other forms can you apply?" Through such self-instructions, we intend the students to reflect upon the procedure applied and for them to assess the steps performed, as well as for them to specify another way of arriving at the answer, if they are able to.

Performance Assessment

The first question, How do I justify the answer I found?, focuses on the students assessment of their procedure and interpretation of their achievements, verifying that the answer and the steps chosen to obtain it are correct. These processes are essential to their learning. The last portion of Figures 1 and 2 shows a complete justification of an answer, which also includes operations and representations, showing how the procedure used was the most appropriate for obtaining the answer.

The students express their justification by a way of a combination of a narrative with the operations and partial results up to the final answer. In Figure 1 the Student A explains that the area of "both triangles is 6..." and "...when added is 12 ..." clarifying in brackets "the area of the rhomboid" to point out which figure the student is referring to, finally adding "multiplied by 3 gives 36 (the area of the square)", using brackets to confirm that the measure corresponds to that shape. Although this description does not establish that the unit of measurement is in cm^2, it correctly refers to the area of the polygon in the final answer.

We observe that the students did not produce a perfect narrative of their justification, but they all assess their performance in positive terms. They are confident of the answer they obtained and that the procedure they applied was the most appropriate for obtaining the solution to each problem. We believe that this occurs because students do not always perform activities after solving a problem. In most cases, they find the answer and that is the end of the task.

Recapitulation and Reflection on the Process

The second and third questions of the post problem resolution activities, lead students to reflect on the process and, in particular, to finding other ways of arriving to the same answer. We joined our analysis of the answers to the last two prompts because the first one generated a closed yes or no answer-Is this the only way of arriving to the answer?- and a yes lead to the last question -What other forms can you apply?, but when the answer was no, the students omitted the final prompt.

Another activity representative of metacognitive skills is activated in this last part of the problem resolution, namely "verification of the result", which is performed by calculating the result in a different way (Veenman 2006). In the teaching experiment, it was applied by asking the students to find another strategy that they could use to reach the same answer. Through the last two self-instructions, we intended to lead the students to reflect upon and assess the process they undertook, and to compare the different procedures they could follow to arrive to the solution.

The above can be highlighted by reviewing Figure 2, where the Student B is seeking another procedure for finding the answer "another way is to NOT divide into 2 triangles...", using capital letters to establish that the above procedure should not be used, and then continues by stating "but directly get the area of the rhomboid which we know is $\frac{1}{3}$ of the area of the square ..." and then uses the formulas for obtaining the areas of the square and rhomboid, substituting the measurements of the known segments and arriving at the answer to the problem again.

Up to this point, we have examined the activities performed by the ten students who participated in the teaching experiment, at the beginning, during execution and after solving each problem. We note that all of the students followed the self-instructions proposed in the experiment, although with different ability levels. That is to say that some followed a broader path while others a narrower path. Likewise, in some cases students worked on problems in a group in order to facilitate the process, but still met all of the requirements requested by them. This shows how they are guided by the self-instructions in an induced manner when solving each problem, thus obtaining an active regulation of their metacognitive skills and favorable results from each activity. In addition, we were able to verify this by way of their narratives on each worksheet.

Conclusions

Through use of self-instructions, students gradually incorporate writing as a support tool throughout the activities. They are invited to use it repeatedly on their worksheets, and although they may consider writing to be merely a means of communication, it actually provides them with the entire control and regulation support during the problem resolution process.

The self-instructions (for the beginning, during execution and after the problem resolution) involve a detailed procedure for the student; indeed a plan of action that occurs step by step in solving the problem. Pupils are helped by the way of the self-instructions to identify difficulties in comprehension, as well as to apply their skills so as to compare and reasonably organize the information, predict inference and reach conclusions.

In the resolution process, students are using cognitive and metacognitive strategies that are useful in the problem resolution procedure. Additionally, writing helps them analyze and reflect on the path they followed to obtain the answer, and demonstrate its correctness. When this path is followed, directed by self-instructions in problem resolution -based on writing- the student monitors, encode and establish processes in a reflective manner, strengthening their learning. In fact, it is a process of self-regulation.

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