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Effects of Topic Familiarity on Analogical Transfer in Problem-Solving: A Think-Aloud Study of Two Singular Cases

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We conducted a qualitative research of case studies based on think-aloud protocols. The aim was to carry out in-depth analyse secondary students' cognitive difficulties appearing in early stages of transfer processes in problem-solving. The task was to relate several source problems to a target problem, in order to solve it effectively. Source and target problems had different Surface and/or Structural similarities. In this paper, the solvers' high or low Familiarity with the problem stories on transfer processes was also focused on. Two emergent instructional phenomena are described, both associated to specific students' cognitive obstacles to achieve success in solving the target problem: the 'Screen effect' and the 'Sisyphus effect'. The obstacles were harder for low Familiarity problems.

Keywords: science and mathematics education, problem solving, analogical transfer, surface and structure, familiarity, think-aloud protocols

INTRODUCTION

Problem-solving by transfer

Word problems, in particular those well-structured of algebraic nature, are one the most used tools to foster and to assess deep comprehension in science and mathematics education. Two main components have been defined in problem-solving (Newell and Simon, 1972): comprehension and resolution. Comprehending a word problem implies the elaboration of mental representations of the problematic situation at different level of elaboration. Kintsch and colleagues, (Kintsch, 1998; Kintsch and van Dijk, 1978; Kintsch and Greeno, 1985; Nathan, Kintsch and Young, 1992; Greeno, 1989) proposed several levels: Word level; Semantic level; Situation Model, or referential level (SM onwards) and Problem Model, or abstract level (PM onwards). The integration of the semantic content with prior knowledge is necessary to build the top representations, SM and PM. They both differ in their constituents. SM is made from non-abstract, ordinary world objects and events, and also world rules, whereas PM is made from abstract entities as relations among quantities, functions, concepts, laws, principles, etc. Resolution implies connecting SM and PM in particular and defined ways. As SM is usually easier to build than PM, the instructional work mainly focus on this SM→PM transition, called '*algebraic translation*' when problems are of algebraic nature (Puig, 1998; Sanjosé, Solaz-Portolés and Valenzuela, 2009; Polotskaia, Savard, & Freiman, 2015).

A well-known and wide-used instructional strategy in problem-solving is "analogical transfer" (Hammer, Elby, Scherr and Redish, 2005; Mestre, 2003; Bernardo, 2001; Bassok and Holyoak, 1989; Reed, Dempster and

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State of the literature

- The study aims to to carry out in-depth analyse secondary students' cognitive difficulties appearing in early stages of transfer processes in problem-solving. Detailed interviews are conducted.
- Problem-solving by "analogical transfer" is a well-known and wide-used instructional strategy. Teacher first solves a coherent set of 'source' problems and next he/she proposes analogous problems to be solved by his/her students.
- Surface, Structure, Familiarity and Unknown are the main problem characteristics influencing students' comprehension and solving procedures.

Contribution of this paper to the literature

- The present study is developed in two steps. First, a sorting task with a set of problems shows the initial students' criteria to consider two problems as sharing their solving procedure. Second, in an individual interview, several 'source' problems are provided to help the student solve a 'target' problem. Source and target problem are related by different characteristics.
- Think aloud protocol is used to obtain solvers' mental processes.
- Two emergent educational phenomena are described, both associated to specific students' cognitive obstacles to achieve success in solving the target problem: the 'Screen effect' and the 'Sisyphus effect'.

Ettinger, 1985; Gick and Holyoak, 1983). In a typical instruction by analogical transfer, the teacher first solves a coherent set of example problems ('source' problems onwards), and next he/she proposes analogous problems to be solved by his/her students ('target' problems onwards).

Students are expected to abstract suitable principles and solving procedures from the examples, and to apply them consistently to solve target problems (transfer). When source examples and target problems are perceived as dissimilar, transfer becomes difficult (Klausmeir, 1985). Thus, success in problem-solving by transfer depends on the solver's ability to establish suitable analogies among problems (Gentner, 1983; Reed, 1987). On the basis of these analogies, the solver is expected to build the abstract mental representation, PM for the target problem, similar to the one constructed for the example(s) considered as 'source(s)'. Specifically, this implies the path shown in Figure I. This path is possible when the connection SM (source) → PM(source) has been explicitly built before, in instructional sessions.

This paper focuses on the crucial first step in Figure 1. Our research questions are:

1) Can the more or less solvers' familiarity with the problem stories difficult building suitable analogies between problems?;

2) How can the problems characteristics difficult or facilitate analogy construction in familiar and non-familiar problematic situations?

Problem Features and Its Interaction with Solvers' Knowledge

The first research question focuses on the concept of Familiarity. The solver's Familiarity with the (problematic) situations described in the statements ('Familiarity' onwards) can be defined as his/her previous experience and (non-abstract) knowledge about the spatio-temporal contexts, objects, events, agents and actions… The lesser solver's knowledge on the situation described in the statement, the poorer the SM mental representation built and the lower possibility of successful solving. Coherently, Familiarity has been considered as one of the strongest predictors of success in problem-solving. In addition, transferring solving abilities from familiar to non-familiar situations are not easy (Jonassen, 2000). This is a relevant point in Science education because teachers usually expect that learning problem-solving procedures in math classes will significantly increase students' success in science problem-solving. However, verbal problems in mathematics usually refer to daily life (familiar) contexts whereas science problems usually do not (non-familiar contexts).

Transfer difficulty inside familiar or inside non-familiar contexts have been also compared. Mayer and Wittrock (1996) sustained that routine and more familiar problems are easy to transfer, whereas transferring non-familiar problems requires more and a conscious effort. Problem-solving difficulties are higher when Secondary solvers have less familiarity with the problematic situations (Gómez-Ferragud, Solaz-Portolés and Sanjosé, 2013a). Therefore, cognitive processes implied in analogical transfer dealing with familiar or non-familiar problematic situations seem to be different. We will try to discover some of these differences in the present study.

Our second research question concerns the problems characteristics. Gómez-Ferragud, Solaz-Portolés and Sanjosé (2013b) found that most Secondary students have difficulties to filter irrelevant problem features out, just keeping only the ones relevant to solve them. Long time ago, Holyoak (1984) differentiated two main kinds of problem characteristics: Surface and Structure. Surface elements are irrelevant to formally solve the problem. Surface features are syntactic variables, objects and events,

SM(target) → SM(source) → PM(source) → PM(target)
(analogy) (instruction) (inferred)

Figure 1. Path to connect SM to PM for the 'target' problem using analogical transfer.
Note: SM and PM stand for 'Situation Model' and 'Problem Model' mental representations.

Table 1. Relationship among the 'target' problem and the analogous, 'source' problems, according to their surfaces, structures and unknowns. Low familiarity condition.

STRUCTURES SURFACES	UNKNOWNS	Meeting	Catching-up	Mixtures
Balloons-Gases	grams	TARGET		REL2
	kilocalories		SIM1	
Electric-Capacitors	microcoulombs	ISO1		
Tanks-Liquids	grams	ISO2		REL1

Note: ISO stands for 'isomorphic', SIM stands for 'similar' and REL stands for 'related'. Indexes 1 and 2 respectively correspond to far and near analogous.

numerical quantities and magnitudes, defining the context and problematic situation in the ordinary world. Structure is the abstract, mathematical nature of the problem. In an algebraic problem, structure is determined basically by "*how the quantities are related to each other rather by what the quantities are*" (Novick, 1988, p. 511). The problems considered here are of algebraic nature so their equations summarize the relations among the quantities, including the unknown.

Different characteristics of the unknown have been proven to cause different solving behavior in novice students, as its position in the statement (Castro, Rico, Batanero and Castro, 1991), its algebraic or arithmetic role, or the name of the unknown magnitude (Gómez-Ferragud, Solaz-Portolés and Sanjosé, 2013c).

The Present Study

We tried to advance in the answers to the above research questions by developing a qualitative in-deep cases study, based on think-aloud protocols. Participants were interviewed individually and a think-aloud protocol was followed to collect detailed data about their cognitive processes in familiar and in non-familiar problematic situations. We concentrated on mental processes associated to building analogies (Clement, 1988) and differences between problems. Among the group of participants, two cases have been selected here due to their singularities and virtual contributions to instruction improvement. Along the interviews students showed different obstacles associated to problems surfaces, structures, unknowns or familiarities, and these difficulties shed light on the answers to the research questions.

METHOD

Participants

Twenty-one, 9th-grade, male and female students of an intact group in a public Spanish school participated in this qualitative study. The educational center was located in a medium-size city (about 80000 inhabitants) in an intermediate socio-economic level zone. Even knowing it was a convenience sample, these students did not show any special feature compared to the average population in Spain.

Design and Materials

Two different tasks were developed in two steps. First, students performed a sorting problems task (Chi, Feltovich and Glaser, 1981). They had to sort 8 (unsolved) word problems and to define groups according to their mathematical solution (Gómez-Ferragud, Solaz-Portolés and Sanjosé, 2013c). The aim of this task was to activate basic cognitive processes implied in problem-solving by analogical transfer: codifying, indexing and mapping problems. Performance in this task was the starting point of the second and main part of this study.

The second step in this study was devoted to analyze, in some detail, the possible effects on analogical transfer processes due to the solver's greater or lesser familiarity with the problematic situation. Individual semi-structured interviews were carried out. Participants were asked to explain aloud their thoughts, judgments and feelings along the second task: relating one to-be-solved 'target' problem to several analogous 'source' problems in order to determine what source problem(s) would provide suitable help to solve the target problem, and the reason why. Five source problems, 3 far-analogous, and 2 near-analogous were considered. As stated before, the problems used in this study were

Table 2. Constitutive elements and algebraic translation of a problem statement in the low familiarity condition

Surface Elements	
Objects: Balloons, pneumatic pumps, gas, container. Events: Consider two balloons; Connecting two identical pneumatic pumps simultaneously; Taking gas off; Putting gas inside; Diminishing the volume; Increasing the volume; Gas transfer.	
Involved magnitudes: cm^3; g; cm^3/g	Unknown magnitude: grams
Ideas having structural relevance	Algebraic translation of the structurally relevant ideas
1- The balloon A decreases its volume at a ratio of 20 cm^3/g	$\Delta V_A = -20\ \Delta m_A$
2- The balloon B increases its volume at a ratio of 30 cm^3/g	$\Delta V_B = +30\ \Delta m_B$
3-Before connecting the pumps, the volume of the balloon A is 2000 cm^3	$V_A = 2000 - 20\ \Delta m_A$; after the pumps were connected
4- Before switching on the pumps, the balloon B is empty.	$V_B = +30\ \Delta m_B$; after the pumps were connected.
Question	Algebraic translation of the question
How many grams of gas will be transferred from A to B when their volumes are the same?	Find Δm_B when $V_A = V_B$

Table 3. Interview procedure in the think-aloud sessions

Phase 1: Revision of the criterion used in the sorting task Delivery of the performed task to the student; reading and recall of the criterion used; explanation of this criterion or of a new one, if it is the case.
Phase 2: Analogies and differences between source problems (only the statements without solutions) and one target problem Handing the target problem in and proposing the task; reading and clarifying doubts. 2A: Handing the three source far-analogous problems (SIM1, ISO1 and REL1) in and placing them in equidistant positions from the subject; reading and clarifying the problems; Student's comparison among problems, especially between each source and the target problem; confirming the kind of perceived analogy/ difference between problems. 2B: When the student was not able to give an answer, or he/she showed a low reliability doing it, the interviewer handed two additional source near-analogous problems (ISO2 and REL2) in and re-stated the task.
Phase 3: Analogies between problems making explicit the full solutions for the source problems Giving the source problems full solved; same procedure than in phase 2; student's final answer.

defined by 4 factors: *a) Surface; b) Structure; c) Unknown and d) Familiarity*.

Two levels of Familiarity have been considered: problems with scientific contexts were expected to create a low familiarity level condition, whereas problems with daily life contexts were expected to create a high familiarity level condition. Table 1 displays the relationship between the target problem and the different source problems used in the low familiarity condition. The source problems have been labelled using the Reed's (1987) nomenclature according to their surface and structural relationship with the target problem.

Appendix shows all the problems used in the low and in the high Familiarity conditions.

Table 2 shows the surface and structural analysis for one problem used in the low familiarity condition. Some key-ideas have been underlined for latter identification. These underlined key-ideas are not enough to determine the equations, as can be verified by comparing the target and isomorphic problems to the related problems in the Appendix.

Procedure

Permission was obtained from parents and tutors to develop this study, in particular the individual interview. For each familiarity condition, the sorting task was carried out in a usual classroom session (30min). After reading the instructions, students completed a practice example. Then, they dealt with the 8 statements in order to sort them according to 'the way they have to be solved' (Gómez-Ferragud, Solaz-Portolés and Sanjosé, 2013c, 2013d).

The individual interviews initiated 7-10 days after the sorting task was done and extended for 2-3 weeks. Each participant was interviewed twice, for low and high familiarity conditions. Sessions were video-recorded.

Video-camera was placed in such a way that the students' actions were recorded, but not their faces. Each problem on the table had different color, so they were easily distinguished when the recordings were visioned and analyzed.

Interviews lasted about 15-25 min. One of the researchers (CG) was the interviewer. The interviews followed a pre-defined three-phases-protocol as shown in Table III. However, this protocol was slightly modified to fit every case and situation. The interviewer read the instructions to the student, and informed him/her about the tasks and its goal. Subjects were also informed about possible interviewer's breaks to ask them to express their thoughts aloud, but never caused by positive or negative judgments about the student's performance.

Codifying the Students' Behaviour

We used the codification categories proposed by Codina, Castro and Cañadas (2011, pp. 160-161). These authors, in turn, based their categories on the Artzt and Armour-Thomas' (1992) paper, and also in Schoenfeld's (1985) previous work. Execution of the solving procedure (resolution) was the last episode not considered here, because we were interested in the analogy construction only. According to the task proposed to the students in this study, we developed the Exploration episode to consider Clement's (1988) stages in analogy construction in science problem-solving: a) generating an analogy/difference among source problems or between a source problem and the target (AG/DG); b) discussing the generated analogy/difference (AD/DD); c) using the analogy/difference to solve the target problem or to understand it. (AU/DU).

CASES STUDY AND DISCUSSION

Different effects coming from the subject's familiarity with the problematic situation on the analogy construction were found. Some students were not affected by the greater or lesser familiarity with the problematic situation. These subjects can be classified in two extreme groups: a) students able to establish structural similarities and differences among problems, filtering-out surface features, as experts do; b) students unable to access the problems structure whatever the level of familiarity. However, most students were influenced by the level of familiarity, so they changed their behaviour from low familiar contexts to high familiar contexts. In this paper we analysed two interesting cases whose behaviour changed from low to high familiarity.

In the following transcripts the most informative segments have been selected due to space limitations. Subjects (S) and interviewer (I) literal verbalizations (but translated from Spanish into English) have been differentiated. Square brackets and italics are used to indicate subject's evident but silent actions. Discussions and comments are stated in different letters and usual brackets for their easy location when they are inserted in the dialogs. Codes have been also included when it was applicable: AG/DG (analogy/difference generation); AD/DD (analogy/difference discussion); AU/DU (analogy/difference use). Problems are labeled using capital letters (TARGET, SIM, ISO and REL). The recording time (min:sec) has been added to every information segment. In order to facilitate comparisons, subject's behaviour in low and high familiarity has been organized in parallel columns.

Case "MLR": Surface similarities hide structural differences between problems: the 'Screen Effect'. A low or high Familiarity implies more or less 'opacity in the screen'

The 'Screen effect' has been defined as the impossibility of detecting structural differences between problems due to their surface similarities, although the student is able to understand such differences (Gómez-Ferragud, Solaz-Portolés and Sanjosé, 2013d). The surface elements act as a screen hiding the problems structure to the solver.

In the low familiarity condition, MLR used the name of the unknown (related to the science topic involved) to classify problems, which is a surface criterion. At the beginning of phase 2, the student took the same surface feature to relate problems.

In the high familiarity condition, MLR found less (but some) obstacles and used a different sorting criterion: problems had the same or different key-ideas in their statements. These key-ideas are the ones underlined in Table 2 and have structural relevance. Now, this student did not consider "litres" and "euros" important to determine the way problems are solved. In phase 2, MLR used the same indicator at the beginning of the second task.

At the end of phase 2A in the low familiarity condition, *MLR* built an analogy between TARGET and REL1 based on a surface feature: the name of the unknown magnitude. She did not mention any structural element. These two problems having the same unknown operated as a 'screen' hiding the structural, relevant features to her. The student looked so confident on her criterion that the interviewer decided to provide her with the solution of the target problems so starting phase 3 (see below).

At the end of the same phase 2A in the high familiarity condition, some obstacles caused by the name of the unknown magnitudes remained. This seemed to create an obstructive REL1-TARGET similarity as *MLR* did not mention any REL1-TARGET structural difference. Thus, the 'screen' was still present. However, the student was able to perceive other similarities and differences related to the meaning of the key-ideas (underlined in Table II) having structural relevance. On these key-ideas she established a TARGET-ISO1 similarity and a TARGET-SIM1 difference. The specific meaning of these key-ideas was

Table 3. Phase 2A. Case "MLR". Fragments from the interview showing differences between low and high familiarity conditions

Low Familiarity	High Familiarity
Phase 2A: Transfer task. One target and three source far-analogous problems are handed in	
MLR studies the TARGET first. Then, takes the source problems one per one and read them carefully. When she finishes, she considers again the REL1 problem. I: [08:06] Why did you return on this particular problem [*he points his finger at REL1*]? S: [08:07] Because in these other two problems *[she points SIM1 and ISO1*] the given units are different from the TARGET. (DG: She focuses on the name of the magnitudes to establish differences between problems). S: [08:21-08:50] I'm going to read the third one [She re-read REL1 and *ISO1, and compares both to the TARGET. Then, she takes ISO1 away and keeps REL1 in front of her, studying it in some detail…* S: [08:51] This one [*pointing her finger at* REL1] is the one I find more similar! (AG: REL1 and TARGET have the same magnitudes and also share some ideas in their statements. However, both problems have different structures). I: [08:53] Could you tell me exactly why? S: [09:00] Yes. Although in one there are balloons and in the other one there are tanks with dissolutions, … (DG: She explicitly mentions some irrelevant differences between TARGET and REL1…) …they both ask the same question. (AD: … but focus on the unknowns as the relevant components). The problem I have to solve ask me the 'grams' and this one too [*she points at REL1 placed in front of her*]. In addition, they both have the same units in everything (*sic*).	*As in low familiarity, MLR reads the TARGET first and then the source problems in order.* I: [03:34] What have you seen in the problems? S: [03:39] This problem [*ISO1*] seems to have the same structure than this one [*the TARGET*]: first, one thing diminishes and then other thing increases… (AG: Soon mention of problems structure, although she does not explain its meaning). But concerning this problem [*she points at REL1*], I see at a glance that both have the same quantities, 20 and 30… Perhaps it could be of some help even though it is about concentrations…Ups! I see that they do not ask the same thing! … Anyway, perhaps it could be of some help although I see both problems do not ask the same things. (AD/AD: As in the low familiarity condition, the unknowns are still important for her, but now there are other important factors she considers). *S*: [04:09-04:26] Let me see the remaining problem… [*she takes the SIM1, put it in front of her and read it once more*] In this problem, both things (*sic*) are increasing [*she refers to the underlining ideas in Table II*] and then I think it is not useful. (DG: The student focuses on the same key-ideas used in the TARGET-ISO1 relation-ship, to find a difference between TARGET and SIM1). I: [04: 27] Have you found other similarities or differences among these problems? S: [04:28-04:47] No [*after a quick reading*].

Table 4. Phase 2B. Case "MLR". Fragments from the interview showing the student's detection of the structure in the high familiarity condition

High Familiarity only
Phase 2B: transfer task (extension): two new and near-analogous source problems are provided.
The interviewer provides the new source problems and let the student read them at their own pace. I: [05:58] Have you found something interesting in these new problems? Anyone could help you to solve the target? S: [05:59] I have seen that these problems [*she points at REL1 and at REL2*] have the same structure and both are related with 'concentrations'… However, this one [*ISO2*] is like the blue one [*ISO1*] because it tells that something decreases and something increases. (…) I: [06:10-06:25] I have a question for you. The target problem asks for the litres of water, while the yellow and the blue problems, (the problems that could help you in your opinion), ask for litres or air and for Euros… Do you think it is important to solve the target or not? S: [06:40] [*The student takes some time to think about before giving an answer*] No, I guess, because the structure is the same no matters the problem asking.

not explained at the end of phase 2A, therefore the interviewer decided to provide the subject with two additional source, near-analogous problems, ISO2 and REL2 (see Table 4, Phase 2B).

The student had the opportunity of comparing couples of source problems (far to near analogous) and then captured new correct similarities between them (AG). This fact supports previous findings about the importance of having enough quantity of source problems to deal with, to abstract the underlying shared structure (Gick & Holyoak, 1983; Goldstone & Sakamoto, 2003). Finally *MLR* discarded the name of the unknowns as relevant factors and kept the 'structure' as relevant, although it meaning was not yet clear. As the similarities between source problems do not imply similarities between any source and the target problem, this last relationship was still implicit at the end of phase 2B.

In phase 3 (see Table 5), the solutions for the source problems were provided to the student.

In the low familiarity condition, *MLR* was not able to access to the problems structure, and then she proposed unhelpful analogies between problems based on the magnitude of the unknown in each problem. However, when the solutions for the source problems were hand in to her, she had no obstacles to understand the algebraic content, and to correctly relate the equations to the statement ideas. When she studied the equations for the source problems, she changed their first criterion and based the analogies on the structure factor. She was not able to make the transition Statement → Equations (the 'algebraic translation'), due to the 'screen effect'. Nevertheless, when the 'screen' was put away, the student was able to understand the mathematical solutions and relate the equations to the statements, so making the transition Equations → Statement.

In the high familiarity condition, *MLR* showed less but some obstacles to elaborate suitable analogies. At the end of phase 2A, she was not able to properly differentiate ISO1 from REL1 and she was troubled by the name of the magnitudes implied. The 'screen' was still present. With the help of two additional source near-analogous problems, she made source-to-source comparisons based on some explicit key-ideas in the statements having structural relevance. Although these relations were correct, the student's awareness of structural similarities and differences was unclear. The solutions provided for the source problems in phase 3 allowed *MLR* clarify her vague meaning of 'structure' and supported their criterion for the source-to-source relationship. Related and isomorphic problems were clearly detached. Thus, she used this 'success' to reinforce the ISO1 and TARGET relationship, first stated in phase 2A.

Using the 'visual' parallel, for this participant the level of familiarity with the problematic situations seemed to be related to the 'opacity of the screen': when familiarity increased, the 'screen' became less 'opaque' so the student could access to some correct structural relationship between problems, beyond their surface analogies or differences.

Case "SuperMario64": Even though the student makes a great effort to advance, failure and deceit causes a 'Sisyphus effect' in low familiarity condition. Higher Familiarity implies higher likelihood to succeed after the effort

Frequently Science and Mathematics learning implies solving cognitive conflicts coming from alternative frameworks or misconceptions. In fact, the theory of conceptual change suggests promoting and solving students' cognitive conflicts in order to them can reach new, deeper states of knowledge. A lot of educational work is needed for, and long term success in conceptual change is a rare event: students tend to return to their initial mental state when they cannot arrive to a better,

Table 5. Phase 3. Case "MLR"

Low Familiarity	High Familiarity
Phase 3: Transfer with the source problems full solved (not the target)	
MLR studies REL1 first. Then reads ISO1 for long time. I: [12:32] What do you think now? S: [12:34] Well… I think this one [she points at *ISO1*] has the same solution procedure that the target. I: [12:36] Why do you change your opinion? S: [12:41] Because looking at the units… Let me see… Here is different [*the student points at REL1*] from the target problem because says the word 'contains', whereas here *[ISO1]* says 'the voltage decreases at a ratio of…' the same that in the target problem. Now I see that I could use these formulas (sic) *[the equations of ISO1]* here *[in the TARGET]* because even though they have different units, I think both will be solved in the same way.	*The student studies the solutions for the source problems for less time than in the low familiarity condition.* S: [07:04-07:016] As I said before, these two problems [*pointing at ISO1 and ISO2*], with the same structures that the TARGET, have the same equations. However, these two [*pointing now at REL1 and REL2*] do not.

Fragments from the interview showing the moment when the screen is removed stronger and fruitful new cognitive position. In this case, they are involved in a sequence of effort and deceit.

According to the Homer's *Odyssey*, Sisyphus, king of Ephyra (today's Corinth), was punished by gods to roll a huge rock up an abrupt hill. Before he could reach the top, however, the massive stone would always roll back down, forcing him to begin again… and forever, causing him a chronic deception. The 'Sisyphus effect' appears when a student, after doing a hard cognitive effort to go forward in some learning task, enters into cognitive conflict, does not reach a new stable state of comprehension, and then 'falls down' to their initial state, free from cognitive conflict but unacceptable for teachers (Gómez-Ferragud, Solaz-Portolés and Sanjosé, 2013d).

As we can see below, in Table 7, in the low familiarity condition *SuperMario64* made us remember this effort-deception sequence. However, this not happened in the high familiarity condition.

In the sorting task corresponding to both familiarity conditions, this student assumed a mixed 'Surface X Structure' criterion. Thus, surface (and not only structural) elements seemed relevant for him to solve the problems. This guided his cognitive processes at the beginning of phase 2A (see Table 6).

In the high familiarity condition, the student used his first criterion to generate differences between problems. This criterion was based on two features: a) the key-ideas present in the statements (the ones underlined in Table 2), and b) the name of the magnitudes.

In the low familiarity condition, the student made progress along phase 2A. However, at the end of this phase we found evidence of misunderstanding. Although the key-ideas mentioned are of structural relevance, noticing literal similarities and differences in these ideas do not imply detecting structural similarities or differences. Other relevant ideas are also needed to

Table 6. Phase 2A. Case "SuperMario"

Low Familiarity	High Familiarity
Phase 2A: Transfer task. One target and three source far-analogous problems are handed in	
The student takes SIM1 and brings it close to TARGET to read it carefully. I: [04:26]; Have you found anything interesting in this problem? S: [04:28]; This one does not help me E: [04:31]; Why? S: [04:32]; Because in the target, A decreases and B increases, but here [*points at SIM1*], A increases and B also increases. I think I was wrong before [*in task 1 and phase 1*], but now I would change [my criterion]. (AG/DG: The student focuses on key-ideas having structural relevance (underlined in Table II). Different key-ideas imply different solving procedure). I: [04:47]; OK. Please, go ahead. *The subject puts SIM1 aside, and brings ISO1 closer to TARGET. Then, read it.* S: [04:56]; This one is OK because, A decreases, as in the problem to be solved, and B increases… (AG: Analogy generated using the new criterion). I: [05:04]; Ok. Let me ask you an additional question (…). This problem [TARGET] and this one [ISO1] ask you for different things, 'grams' or 'microcoulombs'. However, you told me that ISO1 will help you to solve the target problem, right? S: [05:15]; Yes, because the units do not matter. If A decreases, it decreases in both problems, and if B increases, it increases in both problems. (GD/DD: He explicitly rejects the name of the unknown magnitude as relevant, and strengthens his criterion based on the key-ideas. The student seems to make progress). I: [05.36]; Ok. Thank you. Go on, please. *SuperMario64 brings REL1 close to TARGET, reads the former and compares both problems.* S: [06:14]; This one helps me too, because A decreases and B increases, even though the statement does not say it explicitly. (UG: Evidence of misunderstanding).	*The subject reads TARGET first, then reads SIM1 and compares them both. Next, he puts SIM1 aside and takes and reads ISO1. He puts ISO1 aside too and takes REL1. When he finishes, he re-reads SIM1.* I: [03:07]; What are you thinking about? S: [03:09]; To be honest, I don't know whether anyone could help me or not ... I: [03.17]; Why? Read them carefully, please. S: [03:50]; I think any of the three problems can help me, because when A decreases and B increases as in the target problem, the units are different: 'euros per day', or 'litres of air per kilogram', while in the target are 'litres per minute'. (He keeps on considering relevant the name of the magnitudes. This was the criterion he assumed at the end of the interview in the low familiarity condition).

Note: Fragments from the interview showing the initial student's criterion. Differences between low and high familiarity conditions.

full algebraic translation, and these other ideas bring about the isomorphic/related structural difference.

SuperMario64 needed go on working and the interviewer provided him with the two additional near-analogous, source problems in phase 2B.

In the low familiarity condition, phase 2B, *SuperMario64* detected a key-word, important for structural differences between TARGET and REL2: the 'density'. This fact represented a new hopeful progress, though he couldn't access to the implications at that moment. His answer was not correct as ISO1 and TARGET have different solution than REL1 or SIM2.

Table 7. Phase 2B. Case "SuperMario"

Low Familiarity	High Familiarity
Phase 2B: Transfer task (extension): two new and near-analogous source problems are provided.	
The student reads the new problems in the order ISO2-REL2-ISO2. S: [07:46]; This one [*ISO2*] helps me too because the same happens: A decreases and B increases. I: [07:51]; Ok. *The subject re-reads REL2.* S: [08:46]; This one could be useful too, but now I am not sure, because here appears 'density'. If I follow my rule, as A decreases and B increases, this problem should help me too. I: [09:00]; So, the density makes you hesitate S: [09:02]; Yes. Keeping apart the 'density' these four problems [*he points at ISO1, REL1, ISO2 and SIM2*] are very similar and will be solved in the same way.	*The student reads the new problems in the order REL2-ISO2.* S: [05:00] This one would help me [*he points at ISO2*] (…) because, as in the target problem, A decreases and B increases, and in addition, the unit are the same: 'litres per minute'. I: [05:17]; And the yellow one [*REL2*]? S: [05:20]; No. Though it says extracting from A to B (*sic*), the units are 'litres per ton' of mixture.

Nore: Fragments from the interview showing the student's effort-deception sequence. Differences between low and high familiarity conditions.

Table 8. Phase 3. Case "SuperMario"

Low Familiarity	High Familiarity
Phase 3: Transfer with the source problems full solved (not the target)	
The subject studies the solved problems in the order: ISO1, ISO2, REL2 and REL1. When he finishes, he compares these problems and TARGET for some time. I: [11:25] Therefore, which could help you more to solve the target problem? S: [11.26]; The problems related with 'g/cm³' (AG: Warning! This is a wrong analogy. The interviewer thought that he was near giving the correct answer but the student does not understand). I: [11:28]; Before, you focused on the fact the statement included "decreasing A and increasing B". Nevertheless, when you have seen the solutions, you say that the important thing is the problem deals with 'grams' or 'microcoulombs', don't you? S: [11:45]; Yes, I thought this before. I supposed the units did not change the results. But now, when I can see the different solutions, the ones with the same unit, have also the same solution, and the ones having different units have different results. I: [12:12]; Thus, if you had to choose the problems helping you more to solve the target, what problems would you choose? S: [12:16]; The red and the purple problems [*REL1 and REL2*]. (UA/UD: Using the generated (and wrong) analogy. The student seems to not understand the algebraic solutions).	*The student takes and studies the solved problems in the following order: ISO2, SIM1, ISO1, REL1, REL2 and ISO2. Finally, he re-studies ISO1 and ISO2...* I: [06:31] What do you think about? S: [06:33] Here is something troubling…[*he takes a long time comparing ISO1 and ISO2*] S: [07:34] According to that [*he refers to the solutions*] when the question is the same, and the process is the same, i.e. A decreasing and B increasing, the data (*sic*) do not influence on the problem. (AG/DG: Comparing ISO1 and ISO2 *SuperMario64* infers that the name of the magnitudes is not relevant to solve them (and the TARGET). Therefore, he takes this factor away from his criterion, and keeps only the key-ideas in the statements). I: [07:57] Wait! Do you say that here is not the same question…? [*The interviewer points at ISO1*] S: [08:02] I mean it doesn't matter 'euros' or 'litres' because the structure is the same. I think the problems having the same solution procedure than the target one, are these [*He points at the problems ISO1 and ISO2*]. These can help me but the yellow, red and green ones do not help me because they have different equations. (AU/DU: Once he accepted that ISO1 and ISO2 are the structural analogous to the '*target*', the subject rejects other problems having different equations, as REL1 and REL2, or SIM1).

Note: Fragments from the interview showing the 'Sisyphus effect'. Differences between low and high familiarity conditions.

In the high familiarity condition, the subject used their mixed criterion almost till the end.

As the subject looked confident in his (not appropriate) criteria, the interviewer decided to provide him with the full solved source problems, so starting phase 3, (see Table 8).

In the low familiarity condition, the student's behaviour was very interesting. After an apparent step-by-step advance, he fell down to a former position, unacceptable from the educational point of view. Instead of giving him decisive help, the full solutions provided in phase 3 generated a cognitive conflict in the subject: He was not able to understand the algebraic content or the relationship between the equations and the statement in each problem. Thus, he returned to a free-from-cognitive-conflict mental state, taking the name of the unknown magnitudes as the relevant factor ('Sisyphus effect'). Perhaps, if the interviewer had provided him to some explanation or extra-help (not considered yet in this study), *SuperMario64* would arrive to the educative goal, i.e. full comprehension. The whole process makes us remember a failed conceptual change: the lack of understanding of the new offered scientific ideas caused the student's refusal and maintenance of his former wrong ideas.

In the high familiarity condition, however, this student achieved the educational goal. The well-known situations made him easier focusing on the important factors. After studying the source problem solutions in phase 3, he was able to recognize and use structural features to relate problems properly. Without extra-help from the interviewer, the effort was now successful. Of course, at the end of the interview we got limited evidence of full comprehension because the student did not relate the differences in the equations to differences in some key-ideas in the problem statements. In the *Sisyphus* analogy, it seems that in the high familiarity condition 'the mountain' became lower and the student could reach 'the summit' at least. However, even in the correct place, he was far from a relaxing position yet, so the educational work was not finished.

FINAL COMMENTS

The two cases analysed here in detail support previous results of statistical nature obtained in other studies (Gómez-Ferragud, Solaz-Portolés and Sanjosé, 2013a, 2013b; Abdullah, Halim, & Zakaria, 2014): the solver's level of familiarity with the problematic situations seriously influence his/her mental processes involved in problem-solving by analogical transfer. When the level of familiarity is low, establishing structural analogies filtering-out irrelevant elements is difficult. This seems to happen because there is a great demand of cognitive resources to mentally represent the entities mentioned in the statements. Therefore, there are less cognitive resources free for abstract constructions, as the algebraic ones. Thus, there is less expectancy of transfer success.

The level of familiarity interfered with other factors to generate students' obstacles. Its impact on the subjects' performance was different because the cognitive processes subjects activated along the task were also different. The two cases analysed in the present study suggest that training students in daily life problems does not guarantees success in science problem-solving, even though they have the same structures, as other authors found (Jonassen, opus, cit.). Maths and Science teachers should be aware of this fact in order to adapt their instruction avoiding easy transfer assumptions.

Another educational outcome from the present study is that students probably show a greater variability in their degree of problem-solving incomprehension than expected by teachers. Wrong-solvers should not be considered as just one coherent group but a multiple different cases. In the present study we have presented two solvers with a different obstacles also demanding different type of instructional work to make them reach full comprehension. The 'Screen effect' and the 'Sisyphus effect' are two of the undesired educational situations we could find in the classroom. Being aware of the existence of these cases, teachers could diagnose them accurately and adapt their instructional work to help these students achieve the educational goals.

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APPENDIX

LOW FAMILIARITY CONDITION	HIGH FAMILIARITY CONDITION
TARGET PROBLEM Statement: Consider two different balloons A and B. At the beginning A has a volume of 2000 cm^3 and B is empty. Then, two identical pneumatic pumps are connected to each balloon at the same time. One pump takes gas out of A and puts it inside a big container, and the other pump takes gas out of the container and puts it into B. As a consequence balloon A decreases its volume at a rate of 20 cm^3/g, and balloon B increases its volume at a rate of 30 cm^3/g. Question: How many grams of gas will be transferred from A to B, when both balloons have the same volume?	TARGET PROBLEM Statement: Consider two pools A and B. At the beginning A has a volume of 2000 litres and pool B is empty. Then, two identical hydraulic pumps are connected to each pool at the same time. One pump takes water out of A and puts it inside a big container, and the other pump takes water out of the container and puts it into B. As a consequence pool A decreases its volume at a rate of 20 litres/minute and pool B increases its volume at a rate of 30 litres/minute. Question: How many litres of water will there be in A, when both pools have the same amount of water?
SIMILAR (SIM) PROBLEM Statement: Consider two different balloons A and B. At the beginning A has a volume of 2000 cm3 and B is empty. Then, two identical heat pumps are connected to each balloon at the same time. One pump takes heat out of a big oven and puts it into A, and the other pump takes heat out of the oven and puts it into B. As a consequence balloon A increases its volume at a rate of 20 cm^3/kilocalorie and pool B increases its volume at a rate of 30 cm^3/kilocalorie. Question: How many kilocalories will be transferred to A and to B, when both balloons have the same volume?	SIMILAR (SIM) PROBLEM Statement: Consider two pools A and B. At the beginning A has 2000 kg of water and pool B is empty. Then, two identical hydraulic pumps are connected to each pool at the same time. One pump takes water out of a big container and puts it into A. And the other pump takes water out of the container and puts it into B. As a consequence pool A increases its mass of water at a rate of 20 Kg/min and pool B increases its mass of water at a rate of 30 kg/minute. Question: How many kilograms of water will there be in A, when both pools have the same amount of water?
FAR ISOMORPHIC (ISO1) PROBLEM Statement: Consider two different capacitors A and B. At the beginning A has an electric potential difference of 2000 volts between its poles and capacitor B has 0 volts. Then, two identical circuits are connected to each capacitor at the same time. One circuit takes electric charge out of A and puts it inside a big battery, and the other circuit takes charge out of the big battery and puts it into B. As a consequence capacitor A decreases its potential at a rate of 20 volt/microCoulomb, and capacitor B increases its potential at a rate of 30 volt/microCoulomb. Question: How many microCoulombs will be transferred from A to B when both capacitors have the same potential difference in their poles?	FAR ISOMORPHIC (ISO1) PROBLEM Statement: Consider two money boxes A and B. At the beginning A has 2000 Dollars and B is empty. Then, two banking processes begin at the same time. One process takes money out of A and puts it inside a big money box, and the other process takes money out of the big money box and puts it into B. As a consequence money box A decreases its savings at a rate of 20 Dollars/day and money box B increases its volume at a rate of 30 Dollars/day. Question: How many Dollars will there be in A, when both money boxes have the same amount of Dollars?
FAR RELATED (REL1) PROBLEM Statement: Consider two different ascorbic acid solution tanks, A and B. At the beginning A has a volume of 2000 cm^3 and B is empty. Then, two identical hydraulic pumps are connected to each tank at the same time. One pump takes solution out of A and puts it inside a big container, and the other pump takes solution out of the container and puts it into B. Tank A has an acid concentration of 20 g/cm3 and tank B has an acid concentration of 30 g/cm3. Question: How many grams of ascorbic acid will be transferred from A to B when both tanks have the same volume?	FAR RELATED (REL1) PROBLEM Statement: Consider two balloons A and B. At the beginning A has a volume of 2000 cm3 and balloon B is empty. Then, two identical pneumatic pumps are connected to each balloon at the same time. One pump takes gas out of A and puts it inside a big container, and the other pump takes gas out of the tank and puts it into B. Balloon A has an O2 concentration of 20 l/kg of air and the balloon B has an O2 concentration of 30 l/kg of air Question: How many liters of O_2 will there be in A, when both balloons have the same amount of gas?

NEAR ISOMORPHIC (ISO2) PROBLEM Consider two different ascorbic acid solution tanks. A and B. At the beginning A has a volume of 2000 cm3 and tank B is empty. Then, two identical hydraulic pumps are connected to each tank at the same time. One pump takes solution out of A and puts it inside a big container, and the other pump takes gas out of the container and puts it into B. As a consequence tank A decreases its volume at a rate of 20 cm^3/g, and tank B increases its volume at a rate of 30 cm^3/g. Question: How many grams of solution will be transferred from A to B when both tanks have the same volume?	NEAR ISOMORPHIC (ISO2) PROBLEM Statement: Consider two balloons A and B. At the beginning A has a volume of 2000 litres and balloon B is empty. Then, two identical pneumatic pumps are connected to each balloon at the same time. One pump takes air out of A and puts it inside a container, and the other pump takes air out of the container and puts it into B. As a consequence balloon A decreases its volume at a rate of 20 l/minute and balloon B increases its volume at a rate of 30 l/minute. Question: How many liters of air will there be in A, when both balloons have the same amount of air?
NEAR RELATED (REL2) PROBLEM Statement: Consider two different balloons A and B. At the beginning A has a volume of 2000 cm^3 and B is empty. Then, two identical pneumatic pumps are connected to each balloon at the same time. One pump takes gas out of A and puts it inside a container, and the other pump takes solution out of the container and puts it into B. Balloon A has a gas density of 20 g/cm3 and balloon B has a gas density of 30 g/cm3. Question: How many grams of gas will be transferred from A to B when both balloons have the same volume?	NEAR RELATED (REL2) PROBLEM Statement: Consider two pools A and B (containing clay mixed with water). At the beginning A has a volume of 2000 tons and pool B is empty. Then, two identical hydraulic pumps are connected to each pool at the same time. One pump takes mixture out of A and puts it inside a container, and the other pump takes mixture out of the container and puts it into B. Pool A has a concentration of 20 l/kg of mixture and pool B has a concentration of 30 l/kg of mixture Question: How many liters of water will there be in A, when both pools have the same amount of mixture?