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► **To cite this version:**

Evelyne Cauzinille-Marmèche, Gérard Collet, Antoine Cornuéjols, Andrée Tiberghien. Co-Adaptation of Students' Knowledge Domains when Interpreting a Physical Situation in Terms of a New Theory. 2nd European Conference on Cognitive Science (ECCS-97), Apr 1997, Manchester, United Kingdom. hal-02482261

**HAL Id: hal-02482261**

**<https://hal.science/hal-02482261>**

Submitted on 17 Feb 2020

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# **Co-Adaptation of Students' Knowledge Domains when Interpreting a Physical Situation in Terms of a New Theory**

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## **ABSTRACT**

In the context studied here, learning occurs in response to an interpretative task where the theoretical model is provided in a declarative format to the learners. Consequently, learning foremost implies setting up matches between the knowledge associated with the perception of the world and entities of the new knowledge domain, all being subjected to constraints from both knowledge domains. We have gathered evidence about failed attempts at matches by the subjects, and the "repair strategies" they use to overcome these obstacles, consisting mainly in changes of the knowledge representation primitives, activation of new classes, and creation of new ones.

### **Keywords :**

Knowledge acquisition, didactics, learning complex knowledge, semantic matching, teaching of energy concept.

## **INTRODUCTION**

In the research reported in this paper, we focus our attention on the learning of a new knowledge domain by highschool students. We have centered our investigation on the processes at play when two knowledge domains are confronted, one, the world of immediate perceptions, common sense knowledge and heretofore learned models, and the other, a new theory presented in a declarative format. The acquisition of this new theory can potentially transform the way some aspects of the world are interpreted and perceived. Learning is therefore considered as the acquisition of a new interpretative (and predictive) model of the world, by contrast to the acquisition of new categories or problem-solving strategies, and it is effected by the operationalization of a

given declarative theory implying both learning to identify the terms of the theory and learning to make it effective.

New concepts, in this setting, cannot simply be added to the existing ones, they need to be articulated with the former knowledge, which means establishing new links with it and stressing what prove to be relevant aspects, but also, in return, modifying existing knowledge. In this process new concepts are to become operational, that is active in the whole interpretative process of the subject.

In this view, learning foremost implies attempts at matching active pieces of existing knowledge with new terms, under the requirements of both the rules of the new theory and constraints of the existing ones. We have therefore studied how different parts of knowledge are activated and how they are made to fit and reinforce each other in specific and controlled problem-solving activities. In this paper, we specifically study the failed attempts, when matches are problematic to the students, and the adaptation or repair strategies used to overcome these difficulties which usually correspond to modifications of the new concepts or the existing knowledge, or both. We make the hypothesis that this is where conceptual learning takes place.

The matches involved here, as well as the "repair mechanisms" that students use when direct matches fail, do not fit into the classical framework, regarding matching and knowledge acquisition, on several basic accounts. For instance, in analogical reasoning (Gentner, 1983, Gentner, 1989, Holyoak & Koh, 1987, Holyoak & Thagard, 1989, Ross, 1989), only homogeneous entities, described within the same language and at the same abstraction level, are considered for matching. This is wholly inadequate to describe processes at work when subjects are struggling with a new conceptual domain, bringing into play knowledge pieces involving different abstraction levels and different backgrounds. In addition to this, most knowledge changes that follow analogical matches are viewed as discrimination or generalization operations whereas the transformations that accompany the interpretation and modeling of physical situations involve more complex knowledge structures and a wider class of processes.

## **TASKS PRESENTATION**

In our study, highschool students (16-17 years old), working in pairs, are introduced to a pre-theory about energy. It is presented in a declarative form with a number of concepts and properties definitions alongside with class descriptions and fundamental principles (see Table 1).

**Energy Theory / Model (Seed)**

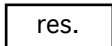

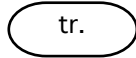
Theory (seed)	Model (seed)
<p><b>Energy</b> can be characterized by :</p> <p>* its <b>properties</b>:</p> <p>- <b>Storage</b> The reservoir stores energy</p> <p>- <b>Transformation</b> The transformer transforms energy</p> <p>- <b>Transfer</b> Between a reservoir and a transformer, or between two reservoirs, or between two transformers, there is transfer of energy. The different modes of transfer of energy from a system to another one are :</p> <p>- <u>by work</u>, There is transfer of energy under the form of mechanical work when there is movement of an object or of a part of an object during an interaction, under the form of electrical work when there is an electrical current (displacement of charges)</p> <p>- <u>by heat</u>, - <u>by radiation</u>.</p> <p><b>Energy</b> can also be characterized by :</p> <p>*a <b>fundamental principle of conservation</b> The energy is conserved whatever the transformations, transfer and forms of storage</p>	<p>To build an energy chain</p> <p>* the drawn symbols are to be used:</p> <p> for reservoir</p> <p> for transfer</p> <p> for transformer</p> <p>by indicating :</p> <p>- in each rectangle the system corresponding to the experiment;</p> <p>- under each arrow the mode of transfer;</p> <p>by putting</p> <p>- an arrow by the mode of transfer.</p> <p>* the following rules are to be used:</p> <p>- a complete energy chain starts and ends with a reservoir;</p> <p>- the initial reservoir is different from the final reservoir.</p>

Table 1. Text given to the students presenting a seed of energy theory/model.

Subjects must then interpret and explain a few physics experiments using this pre-theory, in the process turning it into an operational knowledge domain. (Task 1) Battery - bulb - two wires (Figure 1) ; (Task 2) An object is hanging on a string falls, and a bulb is connected to the terminals of the motor (Figure 2). (Task 3) A battery powers an electrical motor. On the axle of the motor a string is attached. An object is hanging on this string (Figure 2). This implies that connections be established between an existing and compelling perception of the world, the associated knowledge and a theoretic model under construction, all forms of knowledge that are quite disparate. Furthermore, the new theory, because it is described using known terms (such as "heat" or "reservoir"), and the knowledge about objects and events involved in the perception of the situation, are related to other interpretative domains (such as knowledge pertaining to electricity). As a result, the discovery and acquisition of a new conceptual domain not only requires that connections be set up between the knowledge directly associated with the perception of the situation and the theory, but also that this be done in the context of other, diverse and more or less related, knowledge domains (Tiberghien, 1994, 1996).

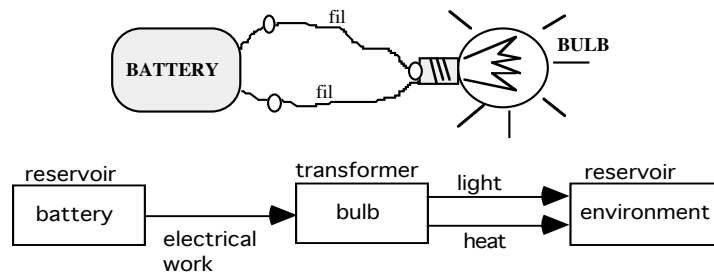


Figure 1 : The first experimental setting and its corresponding energy chain.

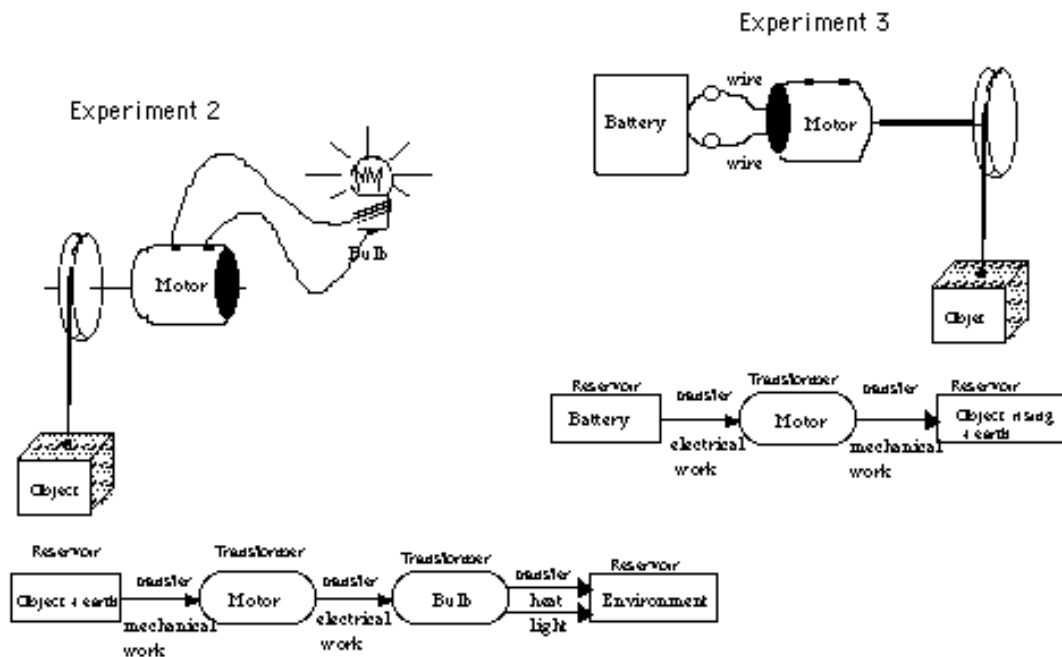


Figure 2 : Experiments (2) and (3) with expert solutions

## METHODOLOGY

Our analysis has concentrated on manifestations of difficulties in the course of the problem solving activity of the students as revealed in the dialogues. We take that a difficulty is encountered whenever there is an interrogation from the students that they are unable to solve immediately. For instance, the following exchange :

Lionel : "A reservoir to start and a reservoir to end"  
 Fulvia : "Do we have two batteries Lionel ?"  
 Lionel : "No !"  
 Fulvia : "So what did we miss ?"

is interpreted as a difficulty to reconcile the needs of the *Theory-Model World* ( $W_{TM}$ ) (demanding that an energetic chain starts and ends with a reservoir) and the perception of the experimental setting, in the *Objets-Events World* ( $W_{OE}$ ), which includes only one battery (currently interpreted as a reservoir). We analyzed in-depth the solving activity of six pairs of students.

## ANALYSIS

The study of the students' **difficulties**, as disclosed from the analysis of the dialogues, shows that it is possible to categorize them into two main classes :

- Difficulties pertaining to the differences between entities that prevent direct matches. Mostly, there are where the "definitional attributes" of entities of each world to be matched do not fully fit.
- Difficulties due to global constraints on the interpretation under construction (for instance, the current interpretation demands that there are two transfers).

When encountering a difficulty, the subjects either can try to retract their attempt and backtrack on other alternatives, or, more interestingly, they can try to adapt their knowledge in order to ease the connection. Again, the **potential changes** can be organized along two categories that closely reflect the classification of the difficulties.

- Changes to the semantical primitives of the knowledge (e.g. modification or suppression of the attributes or creation of new ones, introduction or suppression of links between certain primitives, and so on).
- Changes to the structure of the current interpretation.

It is furthermore possible to distinguish changes according to the knowledge domain involved. There are thus changes that occur within  $W_{OE}$  or within  $W_{TM}$  or that occur in both. There are also changes consisting in introducing intermediary entities.

These changes are effected through procedures that we call *repair strategies*. They are mechanisms employed by the subjects in order to adapt the knowledge or interpretation and satisfy the constraints imposed by the task and the given theory/model. The analysis of the activity of the six chosen pairs of students led us to define three main repair strategies.

- **Change of the knowledge representation primitives** (e.g. addition of properties, modification of the range of the values of a property, deletion of properties, “reification” of a property, addition or deletion of links between certain primitives, etc.).
- **Activation of new classes** (selected through a change of point of view, by dissociation or fusion of new classes, and so on).
- **Creation of new classes.**

In the following, we illustrate some of these strategies, using data from our protocols.

### **Change of the knowledge representation primitives (in $W_{OE}$ and/or $W_{TM}$ )**

#### *Addition of a property*

Example relative to the second task (falling weight). For reasons not to be detailed here, the students are ready to associate electrical wires to transfer. However, they do not find immediately a common definitional attribute (such as mode of transfer). But they know that solar rays are an instance of transfer. They make up an analogy between solar rays and electrical wires, by posing that both have the attribute 'hot', and because this attribute seems related to the reason why solar rays are transfer, they are content to associate, for the same reason, wires with transfer.

The obstacle to the match between an object of  $W_{OE}$ , and a class from  $W_{TM}$  is overcome here by assigning a new attribute to the object of  $W_{OE}$ . This result is obtained by analogical reasoning. There is import of a relevant attribute from another entity in  $W_{OE}$  that is known to be an instance of the entity of interest in  $W_{TM}$ .

#### *Deletion of properties.*

Example relative to the second task (falling weight). The falling weight in task 2 would be a good candidate for being associated with the “reservoir” class of  $W_{TM}$ . However, there is no enclosure for storage in that case. The students choose to ignore this property that, thus far, they always associated with reservoir.

The difficulty is here solved ignoring a property if there are other compelling reasons to match the two entities.

#### *Reification of a property.*

Example relative to the first task (battery - electrical bulb). The students are hinted that solar rays do play a transfer role in a given instance of an energy chain. One prominent property of solar rays is that they are hot. Besides, one mode of energy transfer is 'heat'. Students associate (to the point that they become identified) 'hot' with 'heat', and thus are content that solar rays transfer energy through a heat mode.

In this case, the difficulty is that one property of one entity in  $W_{TM}$  is not shared by a would-be match in  $W_{OE}$ . The repair mechanism consists in reifying this property so that it becomes a property of  $W_{OE}$  and is found in the would-be match.

## **Activation of new classes.**

### **New classes selected through a change of point of view**

A change of point of view regarding one (or more) entities may lead to changing their semantics, viewing them at a more abstract level, or selecting new classes. In the following, we produce three instances of such changes.

#### *Transforming an isolated entity into a relational entity*

Example relative to the third task (rising weight). Ruling out other possibilities, the students are led to the comparison of the rising weight and a transformer. Transformer is a relational concept implying that a mode of energy "before" the transformer be transformed into another "after" form. Students are therefore enticed to look up for energy modes "before" and "after" rising weight. They end up identifying energy mode "before" with work and energy mode "after" with heat (the string would get hot during the rise !).

The difficulty consists in transforming a non relational entity in  $W_{OE}$  into a relational one. The problem is solved by importing the relations from the entity of  $W_{TM}$  to be matched and identify potential candidates in  $W_{OE}$  that could play the role for the relations. This example illustrates the modification of perceiving the  $W_{OE}$  from the point of view of  $W_{TM}$  constraints.

#### *Climbing to a more general point of view by considering superclasses*

Example relative to the second task (falling weight). Falling weight does not have the definitional attributes provided in the  $W_{TM}$  (i.e. storage property). However, there are reasons based on global considerations, not detailed here, why falling weight should be matched against initial reservoir. It happens that (initial) reservoir has increasingly be associated with the abstract superclass Causal\_Agent. And it is indisputable that falling weight is the cause of the phenomena observed in the experimental situation (e.g. rotating motor, enlightening bulb). Therefore, reservoir and falling weight are instances of the same superclass that take a definitional role, and thus they can be matched.

The nature of the difficulty was to find a new definitional attribute between entities of each world to be matched so that they share the same value for this attribute. The repair mechanism consists in finding a common superclass, and take it as a new definitional attribute.

#### *Modifying the semantics of entities and properties by appealing to intermediary concepts.*

Example relative to the second task (falling weight). The students are not sure about the first reservoir. They have learnt that it is a Causal\_Agent, they want to check if falling weight is a Causal\_Agent too. To this purpose, they try to interpret the experiments in terms of the behavior of energy going through the different elements in the experiment. They provide energy with behavioral properties : moving, going through. That way, they satisfy themselves that falling weight is the starting "cause".

The difficulty was to verify that some property is shared by would-be matched entities in  $W_{TM}$  and  $W_{OE}$ . The repair mechanism consists in interpreting this property in modifying the level of a theory concept and giving it properties of the material world. This "new" concept becomes an intermediary between the two worlds.

#### *New classes selected by dissociation of existing classes*

Example relative to the first task (battery-electrical bulb). According to the  $W_{TM}$ , an energy chain includes at least two different reservoirs, one starting the chain and one ending it. Thus far in the dialogue, the students have interpreted the battery as the first reservoir. Now they are looking for the final one. Because of the electrical model where the experimental setting can be interpreted as a closed circuit starting and ending in the battery, they are led to consider the possibility that the battery be also the final reservoir. But then, how to make it different from the starting one ? They end up dissociating the battery into two virtual batteries : a first one, the starting reservoir when the battery is full, a second one, the final reservoir, when the battery is empty.

The difficulty was to satisfy a global constraint on the interpretation that imposes finding in the  $W_{OE}$  world one or more new entities that are copies of an existing one (e.g. having two different reservoirs instead of one currently). The repair mechanism consists in dissociating one existing entity in  $W_{OE}$  to make two or more.

Students consider one entity of  $W_{OE}$  (e.g. the battery) that is currently associated with the entity that must exist in two or more exemplars (e.g. reservoir). They then consider one attribute (e.g. state) of this entity, and specialize (dissociate) that entity by taking two or more different values of this attribute (e.g. state = full; state = empty). Finally, they associate each of these new entities of  $W_{OE}$  to counterparts as required by the constraints. Here again, the modification of perceiving the  $W_{OE}$  is involved

## CONCLUSION

This research calls attention to forms of learning that are not as well documented than generalization, categorization or operationalization of problem-solving strategies are. In the context studied here, learning occurs in response to an interpretative task where the theoretical model is provided in a declarative format to the learners. Consequently, learning foremost implies setting up matches between the knowledge associated with the perception of the world and entities of the new knowledge domain, all being subjected to constraints from both knowledge domains. Our experimental methodology allows to gather evidence about failed attempts at matches by the subjects, and the "repair strategies" they use in order to overcome these obstacles and satisfy the constraints.

Our analysis has brought up three main categories of repairs: change of the knowledge representation primitives, activation of new classes (through a change of point of view, or by dissociation or fusion of existing classes), and creation of new ones. This grid may be useful to interpret how students gradually acquire a new conceptual domain, specially when they have to put in correspondence very disparate entities.

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