Identifying Valuable Components of Student Behavior: Things They Do Right When They Solve Wrong[3]

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Abstract

The present study explores and characterizes some metacognitive abilities of students in an introductory university-level physics course. This characterization is done in the context of solving problems on magnetism. The study is based on a manifold view of cognition as the one in the theoretical framework proposed by Hammer, Redish and others (Hammer & Elby, 2003, Hammer et al, 2005) according to which subjects' cognition is the result of the context-sensitive activation of cognitive resources. Within this framework, metacognition is studied together with subjects' cognitive productions. Results show that students, considered novices, have a series of metacognitive abilities, from which they can construct their metacognitive expertise. This could help to better understand the process by which students do this during their learning processes.

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Introduction

Problem solving is a complex cognitive task, in which metacognitive activity plays an important role. The basic function of metacognitive activity is to control and if necessary redirect the course of cognitive activity. One important finding in metacognition in problem solving is that subjects who have a better performance in the task of problem solving, also exhibit a higher degree of development in their metacognitive abilities. As an example, Gerace (2001) points out that while in novices problem solving uses almost all available mental capacities, experts are able to think about problem solving while problem solving. Howard et al (2001) examine certain metacognitive monitoring and regulatory skills in the context of solving science problems in a computer-based learning environment. These authors were able to establish that metacognitive self-regulation is a good predictor of success at problem solving. On the basis of results such as the ones mentioned, instructional environments have been

[3] Partial results of the present work were presented at the *"2007 Foundations & Frontiers in Physics Education Research Conference"*, Bar Harbor, Maine.

designed to help subjects mimic expert behavior and thus acquire certain metacognitive habits. Reports of these instructional environments show that training students in such metacognitive behavior positively affects their problem-solving performance. Georghiades (2004) introduced metacognitive activities within science instruction through classroom discussions directed at reflective thinking and diary-like notes on students´ reflections on classroom activities. The authors found that students trained with these activities retained the contents taught through a longer periods of time. Berardi-Coletta et al (1995) compare the performance on the solving of a novel problem by two groups of students. The control group received traditional instruction while in the experimental group students were either prompted to describe their actions or to give reasons for them. The purpose of asking for reasons was to bring students' own thinking into their focus of attention. The authors found that students in the experimental group performed better when solving a new problem.

The examples just shown above allow us to pinpoint two important findings of the research on metacognition in problem solving. First, as pointed out by Gerace (2001), metacognitive skills are a component of subjects' expertise. Furthermore, as illustrated by the studies of Berardi-Coletta (1995) and Georghiades (2004), when subjects are "trained" to mimic the metacognitive behavior that experts exhibit, this has a positive influence on their problem solving performance. This indicates that mimicking experts helps students to build their metacognitive expertise. These results, however, do not tell us how students do this.

On the other hand, the cognitive nature of metacognition also often stands in the way of differentiating what should be called metacognitive and not simply cognitive. As some authors point out, the already fuzzy concept of metacognition "has become even fuzzier due to a ballooning corpus of researchers of widely varying disciplines and for widely varying purposes" (Hacker, 1998, p 2).

These two difficulties: a) the fact that metacognitive abilities are known to be characteristic of experts, but it is still not clear how they are constructed and b) that the boundaries between cognitive and metacognitive phenomena is difficult to establish, could be overcome in part if cognitive and metacognitive activities could be regarded as different aspects of the same phenomenon.

Recently, Hammer and others (Hammer & Elby, 2003; Hammer et al, 2005), based on previous results of diSessa & Sherin (1998), propose a view of cognition based on what they call *cognitive resources*. In this approach, when subjects undertake a cognitive task, they activate a subset of their available cognitive resources, in a way that is context-dependent. Thus, subjects' cognitive as well as metacognitive behavior is the result of the activation of these resources. One possible (non-exhaustive) way to classify cognitive resources is to divide them into two categories: *conceptual* resources and *epistemic* resources. The first group, i.e. conceptual resources, is the set of resources that enable subjects to reason about physical situations. An example of one such resource is "*the more, the less*". Mapped onto a particular situation, such as looking at an object at a certain distance, this resource can lead subjects to reason that *the more the distance* from an object, *the less the size* of the object will appear to be. When resources are activated in situations such as these, they are said to be mapped onto the elements of that situation. In this example, the resource *the more, the less* is mapped onto the distance from the observed object and the apparent size of that object.

Epistemic resources are the ones that enable subjects to deal with their available knowledge. When facing a cognitive task, subjects pay more attention to certain traits than to others, and also adopt a particular behavior which they find (consciously or unconsciously) is an adequate response to the situation. Since the activation of epistemic resources is also context-sensitive, the same subject may exhibit different behaviors in different situations. An example Hammer et. al. (2005, p 102) offer for this is the case of a student given the name of “Louis”. This student viewed learning Physics as two completely different cognitive tasks. First he approached the task as one of memorizing “every word of the homework solutions”. After performing poorly on a midterm exam and an interview with one of his tutors, Louis decided to try one of his advisor´s suggestions and think of an analogy he would make up for a ten year old when studying Physics. He realized that he had experience working with children and was able to use the idea of making an analogy in the same way as he would explain something to a 10-year old. As a result he was able to re-structure his ideas about Physics and did significantly better on his next exam. Hammer et. al. (2005) use this case as an example to show how Louis was able to activate the resource of building knowledge from what is already known (by building an analogy) in the context of tutoring small children, and improved the way he learned Physics when he was able to activate this same resource in the context of studying for his exam. The point that is supported with this example is that the ability to use analogies is something that Louis can deploy depending on context, and therefore it is not a unitary cognitive element. Rather, it is the result of activating finer-grained cognitive elements, and this activation is context dependent. It would not be possible to understand Louis´s behavior if the ability to build analogies were considered a unitary cognitive element. This would not allow us to understand why he would not use an ability he has in a situation that calls for it.

When confronted to a cognitive task such as solving a Physics problem, students activate certain conceptual resources to reason about the physical situation, and also epistemic resources to administrate their previous knowledge. Two epistemic resources are of particular interest in the present study. They are related to different stances subjects can adopt regarding their cognitive activity:

Understanding: a student activating this resource will be satisfied with his own description of the situation at hand.

Confusion: activating this resource will allow a student to manifest dissatisfaction due to an internal incoherence between two or more of his/her ideas regarding a given situation.

These resources are closely related to students’ metacognitive activity of *checking*. As Hammer and Elby (2003) point out (cic), “epistemic resources may serve the role of helping to activate metacognitive resources; or they may turn on in response to metacognitive activity, to play an administrative role”. Once more, an appealing feature of a resources-based view of cognition (and metacognition) is that due to the contextual activation of resources, the same subject may activate a different set of (conceptual and epistemic) resources in different contexts, and thus exhibit either an expert-like or novice-like behavior. The shift from novice to expert could then be related to a higher refinement of resources, the generation of new resources, or a higher degree of adequacy in the activation of resources, which enables the subject to efficiently activate the most convenient resources in the situations in which they result fruitful.

Viewing cognition and metacognition as the result of the activation of conceptual and epistemic resources raises interest in describing, from among the epistemic resources students activate, those which enable them to perform metacognitive activities. The activation of these resources, which will be referred to as metacognitive, is what enables students to check and redirect the course of the cognitive task at hand. Therefore, we shall give the name of metacognitive resources to those epistemic resources that, when activated, allow students to monitor and/or redirect the course of their cognitive activity of problem solving. Since this activity is in turn envisaged as the activation of one or a set of conceptual resources, we shall say that the activation of metacognitive resources is what enables students to check their understanding in terms of the conceptual resources they have activated, and eventually to change their activation if necessary. We do not attempt to achieve a thorough description of the metacognitive activities novices cannot do or do incorrectly (as compared to experts). Instead, our purpose is to better comprehend the metacognitive activities they *are* able of engaging in and to be better prepared to design instruction in a way that is more efficient to promote the refinement of those abilities. In terms of metacognitive resources, the present work reports the finding of some metacognitive resources that a group of novices was found to activate during a problem solving activity.

The aim of the study is not to propose an instructional strategy aimed at fostering the mimic of novice behavior instead of expert behavior. The results that we seek are to identify certain resources that could be involved in their (still underdeveloped) metacognitive activity. This will help us understand the process by which students are able to learn, for instance, when instruction favors mimicking of expert behavior.

The Study

This exploratory study aims at the characterization of the metacognitive activity exhibited by students of an introductory university-level physics course, while solving problem situations dealing with topics of magnetism.

Participants

Students participating in the study were Chemistry majors who had recently finished this Physics course which is the second one that they take in the second semester of the first year of their career. The characterization was done on the basis of the metacognitive resources, as well as other epistemic resources, activated by nine students who volunteered to participate in the study. The instruction of these students, during the course, included the topics of forces acting on electric currents in the presence of magnetic fields. An important example of such interactions discussed during the course was that of the torque acting on closed loops of current placed in magnetic fields. In such cases, these loops of currents were described in terms of their associated magnetic moment. In the course these students had taken in the semester immediately before, they had thoroughly discussed the concept of mechanical equilibrium. Examples of mechanical systems in equilibrium included springs holding masses, masses lying on different surfaces, strings holding masses, etc.

Data Collection

Since the study is of an exploratory type, we conducted several interviews, in which the resources we wished to identify could be evidenced. The underlying assumption is that if the activation of a particular resource is evidenced, then we can assume that the activation occurred. Case studies, such as the present one, are not sufficient to support or disregard any particular hypothesis, but are valuable in providing evidence for the existence of elements such as metacognitive resources. The analysis was done following the idea that the activation of epistemic resources can help in the activation of metacognitive resources, and that epistemic resources can in turn be activated in response to metacognitive activity, as already pointed out by Hammer et al (2003). This circular relation between the activation of metacognitive resources and other epistemic resources, and the fact that both epistemic as well as conceptual resources are activated during problem solving calls for the observation of these activations as part of the same phenomenon, and therefore the activation of one type of resource is reported in the context of the others. Another study has been carried out in which the focus was directed at the characteristics of the activation of conceptual resources in a similar setting (Buteler & Coleoni, 2010). As for the methodology used to obtain data, two characteristics of the interviews were relevant:

1. Subjects were interviewed in groups of two (in one case three), in order to favor the flow of verbalizations.

2. Problem statements were not presented at once, as in a printed sheet of paper, but in a sequential manner, sentence by sentence. This also had the purpose of increasing the flow of verbalizations, since students had more time to produce them, and they could be allocated more specifically to each portion of the problem. This way of collecting data sentence by sentence was previously used in another study (Buteler & Coleoni, 2006). Interviewers' participation was limited to keep the flow of students' verbalizations, and occasionally to require clarification, without referring to the correctness of students' productions.

The purpose of the present report is to characterize metacognitive activity in terms of the activation of metacognitive resources. The main assumption sustaining the way data are analyzed is that the activation of certain epistemic resources serves as the basis for the activation of metacognitive resources, which are the ones that enable subjects to carry out metacognitive activities. As a result of this metacognitive activity, different resources (epistemic and conceptual) can in turn be activated. Therefore, analyzing the activation of metacognitive resources requires also reporting the activation of other, conceptual as well as epistemic, resources.

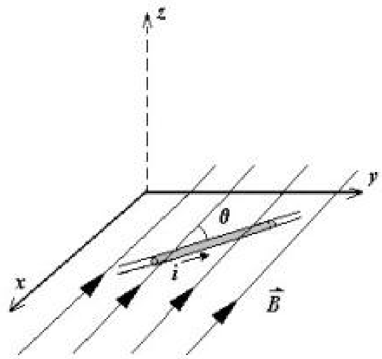
The analysis of data is done on the basis of a case study. We seek to identify the existence of such resources, and to observe their activation in the context of a problem solving situation, i.e. together with the activation of other epistemic as well as conceptual resources.

The problems used

The problems presented to students are shown in Figure I.

Problem A

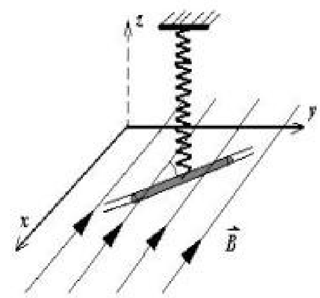
A conducting rod of length $\boldsymbol{l}$ and mass $\boldsymbol{m}$ is placed horizontally in a zone where there is a uniform magnetic field $\boldsymbol{B}$, which is also in the horizonal plane. An electric current $\boldsymbol{i}$ passes through it. The rod forms an angle $\boldsymbol{\theta}$ with respect to the direction of the field, as shown in the figure



Considering that: $\boldsymbol{i}$=0.01 A, $\boldsymbol{B}$=0.3 T, $\boldsymbol{l}$=0.5 m, $\boldsymbol{g}$=10 m/s^2 and $\boldsymbol{m}$=0.045 kg, what is the value of $\boldsymbol{\theta}$ for which the rod will be in equilibrium?

Problem B

A conducting rod of length $\boldsymbol{l}$ and mass $\boldsymbol{m}$ hangs from a spring of elastic constant $\boldsymbol{k}$, as shown in the figure. The space in which the rod is located is affected by a constant and uniform magnetic field $\boldsymbol{B}$. Both the rod and the field are on the horizontal plane.



1. Being $\boldsymbol{k}$=45 N/m and $\boldsymbol{m}$=0.045 kg, How much is the increase in the length of the spring when the rod hangs from it?
2. If an electric current passes through the rod, what will happen to the spring, compared to the situation described above?

Figure I. The problems used in the study

Results

In what follows, excerpts from the transcriptions of students' protocols are presented, to show certain metacognitive resources. These are recognized when activities are identified that enable the student(s) to change the course of their cognitive action, or in other words, to produce changes in the activation of the conceptual resources. The conceptual resources that will be shown in the transcripts are two: balance and alignment:

Balance: activation of this resource allows students to balance the effects of two opposing agents. The activation of this resource is useful to address problems in which one or more agents exert forces on an object in equilibrium.

Alignment: this resource is useful to reason about two entities that rotate in order to align with one another. An example of a fruitful activation of this resource is when it enables a person to understand the alignment of a compass needle with the existing magnetic field; or the alignment of an electric dipole with an external electric field.

As for the metacognitive resources that will be reported, and which are the focus of this study, the first of them has been named *reconciling*, has already been found to be activated in children by Lising & Elby (2005). The other resource found has been given the name "what-happens-if". A definition for both these resources is offered next.

Reconciling. When this resource is activated, the consequences from two different lines of reasoning are reconciled into one coherent description. One possibility, for example is to reconcile the reasoning stemming from everyday experience with the one generated through formal knowledge. Therefore, its activation allows students to check for coherence between available knowledge from different sources.

What-happens-if. By activating this resource, subjects evaluate their comprehension by posing this question and evaluating their own responses. The particular trait of this resource is that that the inference subjects can make by asking themselves this question is not suggested in the situation to be solved.

The activation of these metacognitive resources is seen together with the activation of the epistemic resource of *confusion*. The excerpts presented in this section serve as examples to illustrate this. A summary of the metacognitive resources reported is presented in Table I. The other cognitive resources (conceptual as well as epistemic) that are present in the transcripts are also presented in the same summary.

Table I
Summary of the resources described in the transcripts

	Resource	Description
Conceptual	Balance	activation of this resource allows students to balance the effects of two opposing agents
	Alignment	useful to reason about two entities that rotate in order to align with one another
Epistemic	Understanding	a student activating this resource will be satisfied with his own description of the situation at hand
	Confusion	activating this resource will allow a student to manifest a dissatisfaction due to an internal incoherence between two or more ideas regarding a given situation
Metacognitive	Reconciling	by activating this resource is activated, the consequences from two different lines of reasoning are reconciled into one coherent description
	What happens if	activation of this resource allows students to evaluate their comprehension by posing this question and consider their own responses

The first excerpt presented, corresponding to Ana and Guillermo, is an example showing the activation of *confusion* together with the metacognitive resource *what happens if.* Excerpts 2 (students Claudia and Pablo) and 3 (Valeria, Darío and Gustavo) show the activation of *confusion*, together with both metacognitive resources, *reconciling* and *what happens if*.

Excerpt 1: Both Confusion and what happens if are exhibited

Ana and Guillermo: (while reading problem A)

Interviewer: So, you're saying that to be in equilibrium, it has to be in the direction of the field?...

Guillermo: yes, because then... the force is times the...

Ana: 'cause then there won't be any force

*Guillermo: ...times the sine of theta (*and at the same time)

Ana: ...but... did we say everything wrong?

Interviewer: ...so... that's what you think will maintain the rod in equilibrium...

Guillermo: yes...

Ana: oh!...there's still gravity...

Guillermo: oh, ok... I don't know, 'cause I never saw gravity in these kind of cases

Interviewer: no? What do you mean?

Guillermo: there's a force pulling it down

Interviewer: does the rod have weight?

Ana: sure! (at the same time) *Guillermo: yes!*

Ana: oh! So... what? When the field aligns it… it just… falls down?!

The transcript above shows students activating *alignment* and stating that equilibrium will be reached if θ=0. Ana activates *confusion* (she is not certain of her conclusions: "did we say everything wrong?"). Also, it is possible to see her activating *what happens if*, after noticing that the rod has a finite mass and hence weight. She analyzes what would happen if the rod were allowed to rotate, and notices that it would align with the field, and then fall as a consequence of its weight. This leads her to once again activate *confusion* ("it falls down?!") This metacognitive resource is her response to her state of confusion.

Guillermo: let me see... wait... oh... so, we need a force opposite to that, pointing up 'cause... it has to be aligned with (in the direction of) the weight

Ana: 'cause actually...wouldn't it have to be in equilibrium there? With that angle, in that position, the force pointing up, I mean the force from the field, is the same as the weight… I mean, that's what we have to compute

Guillermo: yeah, we have to see if that's equal to the force from gravity

Interviewer: do you want to do some kind of computation, drawing?

Guillermo: we get 0.45 N for the weight...

Ana: (makes the computation) well, that's the magnitude

Guillermo: yes, the direction is vertical, and pointing down… in the negative z direction

Ana: so this force, magnetic force, has to have the same modulus

Guillermo: but upward... that is, vertical and... pointing up…

Ana: *and the formula for the force was....*

Guillermo: *i times B times l times the sine of the angle… so (they solve for the sine of theta)*

In this part of the transcript, Ana and Guillermo activate *balance*. Even though the complete protocol is not reported, they are satisfied with their solution, and feel they understand the situation, which is interpreted as the activation of the epistemic resource of *understanding*.

Excerpts 2 and 3: the epistemic resource of Confusion and the metacognitive resources reconciling & what happens if

Excerpt 2: Claudia and Pablo (While solving problem B)

Claudia: *(puzzled) mass m… hanging from spring?! (halts)*

Interviewer: *Anything else?*

Claudia: *we never saw anything like this…I mean… that's the first thing we… you look at the drawing and if its something we never saw we go "wow! What's this?!" if its too different, I kind of get scared…*

…

Claudia: *...I'm not so sure about this... I'd have to think some more... hmm, no, I mean, I need to make some computation to... to decide if things happen the way I think they do... 'cause the force on it will pull it up...*

Interviewer: *what force?*

Claudia: *the force of the magnetic field... upward... yes... and all the time, 'cause the field is uniform and constant…*

Pablo: *the current that is passing through there, is it going that way? … right… doesn't say anything, so… what if the current were going that way?… (hands gesturing the right hand rule) it would be pulled down… ok, so we are actually assuming that the current is like in the first problem… but it doesn't really say anything about it.*

These students had carried out a physically correct solution in problem A. When addressing problem B, they make a qualitative analysis of the problem. Having activated the resource of *confusion*, Claudia makes an attempt to *reconcile* her ideas of *balance* with a formal expression, in order to be sure of her assertions (although she does not manifest being confused, she does express a strong uncertainty regarding her ideas). The resource *what happens if* allows Pablo to monitor and refine his understanding in deciding whether the rod tends to stretch the spring further or not.

Except 3: Valeria, Darío and Gustavo (While solving problem B, item 1)

Valeria: it's the same problem... only with that little spring there... well, maybe the angle isn't the same, but its the same problem…

Gustavo/Darío: but it doesn't say anywhere that there is a current through the rod...

...

Interviewer: what's gonna happen there?

Valeria: nothing…

Darío: if there's no current, there is no magnetic moment, and there is no torque

Valeria: and the rod is just gonna stay there, as it is

Interviewer: and the spring… why is it there?

Valeria: just to make things more complicated! (laughing)

Gustavo: (reads first question)

Valeria: what was the formula like?

Gustavo: yeah, for the spring... –k times the distance...

Valeria: oh, yes, times the "stretching"...

Darío: it's the force opposite to the weight...

Valeria: what?!

Darío: thing is... I'm not sure if what I'm saying is right...

Gustavo: yeah but... the field does have to do something on the rod, right? I mean, you don't need a current... if you have something metallic, you put it near a magnet, there is an attraction

Valeria: but... how do you mean? (To Gustavo)

Gustavo: if you put something metal near a magnet, the magnet's gonna attract the metal "thing"

Valeria: if you have a current...

Gustavo: *no! In the fridge door there is no current, and the magnets stick to it*

Darío and Gustavo realize that there is no current passing through the rod (which is an essential feature based on which *alignment* was activated in the previous problem). Also, it is possible to observe Darío activating the conceptual resource of *balance*. This seems to foster the activation of *confusion* in Valeria, and an attempt from Gustavo to *reconcile* this formal description with his everyday experience. Gustavo attempts to *reconcile* two ideas. On the one hand, what they are elaborating from formal elements, and, on the other hand, the activation of a conceptual resource of *attraction* probably influenced by his everyday knowledge that "refrigerator magnets stick to metal doors"[4]

(Darío seems to have something to say, but is hesitant)

Interviewer: Darío, what are you thinking? Tell us...

Darío: *if it says there that the spring is making a force... the force the spring does on the rod is the inverse (for opposite) to the force the Earth does on the rod... just imagine you're hanging the rod on the spring... for it to be in equilibrium, there has to be a force from the spring equal and opposite to... I don't know... that, I know is right, I'm just not sure if it has to do with all this…*

Darío activates a control resource that consists of thinking of a problem similar to the present one. In the context of this analysis, this has been classified as *what happens if.* Thus, he poses the idea of what would happen if one would simply hang a mass/rod from a spring. The fact that he adds "I'm not sure if it has to do with all this" is indicating that the activation of these resources occur together with the activation of *confusion*.

Valeria: *(to Gustavo) why do you say that the field attracts the conducting rod?*

Gustavo: *I may be wrong, but I think magnetic fields attract metals, metals are attracted by magnets, so then the rod would tend to go that way and the spring will have to stretch more*

(What he means, as suggested by his speech and his gestures, is that the rod will be attracted in the direction of the field, and therefore will tend to move in that direction, so the bottom end of the spring will feel a force in the negative x direction. Since the upper end of the spring is fixed, the spring will be further stretched)

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[4] This is further clarified by Gustavo, who explains this idea to Valeria.

Valeria: *and why couldn't it be stretched the other way? (in the positive x direction)*

Gustavo: *well, I'm not sure if it goes with or against the field, but its one of those two possibilities...*

Gustavo keeps trying to reconcile with his experience on magnets clinging to refrigerator doors, and Valeria tries to follow his reasoning. Darío attempts to reconcile his classmates' explanations (basically Gustavo's) with his formal knowledge. Since Gustavo claims that the rod will feel a force in the direction of the field, but cannot decide whether it will be in the positive or negative x direction, Darío then tries to reconcile this ideas of *attraction* with the formal knowledge that magnetic fields are generated by permanent magnets or by currents (via magnetic dipolar moments) He therefore tries to imagine the orientation of the magnet equivalent to the rod, but as there is no current, there is no magnet associated to it.

Darío: *sure, it depends on the field the conductor makes... for that you need to consider the conductor as a magnet too, and see if that magnet will be attracted or repelled by the field... but since there is no current, to me there is no magnet.*

Darío attempts to reconcile his classmates' explanations (basically Gustavo's) with his formal knowledge. Since Gustavo claims that the rod will feel a force in the direction of the field, but cannot decide whether it will be in the positive or negative x direction, Darío then tries to reconcile this ideas of *attraction* with the formal knowledge that magnetic fields are generated by permanent magnets or by currents (via magnetic dipolar moments). He therefore tries to imagine the orientation of the magnet equivalent to the rod, but as there is no current, there is no magnet associated to it.

Discussion

This study shows students´ activation of certain metacognitive resources namely those named as *reconciling*, and *what-happens-if*. These activations occurred together with the activation of the epistemic resource of *confusion*. It was also possible to observe how the activations of different resources are related to each other, and that the activation of the mentioned metacognitive resources can lead to changes in the activation of different conceptual resources.

Also, it was observed that the effect of activating metacognitive resources is not always that of redirecting cognitive activity towards formally "correct" results. Such is the case of Valeria and Gustavo, when after activating the resource of reconciling, keep the activation of alignment or that in any case, an attraction in the direction of the field will be added to the alignment of the rod.

Previous work on metacognition has described certain metacognitive abilities of experts, and that they are related to a good level of problem solving performance. These findings have led to the design of instructional strategies aimed at fostering students' expertise in these abilities. This is often achieved by inducing students to mimic expert behavior. In the present study we intend to make a step forward in understanding *why* this is often successful. That is, we aim at better understanding the process by which students build their metacognitive expertise during such activities. Results from the present study show that students (novices) have metacognitive resources available such as *reconciling* and *what happens if*. These are the basis on which they can build their metacognitive expertise. These findings, along with the fact that other metacognitive resources can be present and described in the future, could allow for a more effective way of fostering their improvement through instruction.

Although the activation of metacognitive resources is seen to occur together with the activation of the resource of *confusion*, some considerations are in order regarding this apparent co-activation of resources. In the case of Valeria, for example, *confusion* does not seem as effective to promote a change in the activation of *alignment* and the activation of *balance*, as is seen with Darío (who activates *balance*) and Gustavo (who activates *attraction*). Also, it is Darío and Gustavo who bring new considerations into the solving process the three are carrying out together. Although they all activate some metacognitive resource when they have activated the resource of *confusion*, they do not do this at the same time. Valeria, for example, maintains confusion much longer than her peers (Darío and Gustavo). Therefore, the question arises of whether *any degree of confusion* is as useful a trigger for a student to activate metacognitive resources.

Another important issue about analyzing students' cognitive and metacognitive productions in terms of the cognitive resources they activate lies in the fact that the productions of students that are usually regarded as mistakes contain valuable information of their potential abilities. Moreover, those resources are the tools they already use to address problem solving, and therefore a sensible instructional decision would be to improve our understanding of those resources and the details concerning their activation. In this respect, further study of students' metacognitive resources should involve situations with the potentiality of generating different degrees of confusion, and analyzing the conditions under which the activation of confusion is favorable for the activation of metacognitive resources. Therefore, analyzing situations in which students are confused should be considered a potentially useful task, just as analyzing the mistakes they make.

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