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Research Article

Is inhibition involved in overcoming a common physics misconception in mechanics?

Lorie-Marlène Brault Foisy [a,b,*], Patrice Potvin [a], Martin Riopel [a], Steve Masson [a,b]

[a] *Département de didactique, Université du Québec à Montréal, C.P. 8888, Succursale Centre-Ville, Montréal, Québec, Canada H3C 3P8*
[b] *Laboratory for Research in Neuroeducation, Québec, Canada*

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ABSTRACT

Science education is often challenged by students' misconceptions about various phenomena. Recent studies show that these misconceptions coexist with scientific conceptions, even after a conceptual change occurs. However, the mechanisms involve in overcoming the interference caused by this coexistence remain poorly understood. A possible explanation is that inhibition could play a role in learning science. An fMRI protocol was used to obtain functional brain images of novices and experts while performing a cognitive task in mechanics, a scientific discipline for which misconceptions are known to be frequent and persistent. The results show that experts, significantly more than novices, activate brain areas associated with inhibition: the right ventrolateral prefrontal cortex and the left dorsolateral prefrontal cortex. This suggests that the experts' misconceptions in mechanics have not been eradicated or transformed during learning; they would rather have remained encoded in their brain and were then inhibited to provide a correct answer.

1. Introduction

An extensive research literature in the field of science education highlights the difficulty for teachers to develop a satisfactory understanding of certain scientific concepts among their students. Students have many conceptions about natural phenomena that are not consistent with scientific knowledge [71], which interferes with their learning [18,54]. These conceptions are often referred to as preconceptions [50], misconceptions [68,87], naive or intuitive rules [4] or simply initial conceptions [23]. Regardless of what they are called, they all refer to the idea of an opposition between a student's conceptions and the scientific conceptions taught in school. For example, students often believe that light objects float whereas heavy objects sink because they only consider the weight factor in their evaluation of buoyancy (instead of considering both weight and volume). [66,90].

It is also well documented that misconceptions often persist even after students have received formal instruction in scientific conceptions [3,46,90]. Initial conceptions are thus considered hard to change [32]. This could be partly explained by the fact that misconceptions can be sufficiently effective and useful in many real-life contexts [53]. According to Houdé [42, p. 173], not only children, but also adults, often prefer to use a simple heuristic, which is "a very fast, very effective strategy—thus economic—which works in a satisfactory fashion, very often, but not always". Preconceptions or heuristics do not always lead to explanations that are scientifically correct and it would therefore be necessary, in some contexts, to overcome them in order to reason scientifically. Given that educational interventions in science often encounter common misconceptions, it is important to take them into account in the study of science learning. In particular, physics seems to be a discipline for which the persistence of misconceptions is especially pronounced. It is a field for which learners' initial conceptions are among the best known and the most difficult to change [14]. For example, even after they received formal education on the subject, more than 25 percent of first-year physics students in bachelor's-level programs still believe that a metal ball will fall to the ground faster than a plastic ball of the same size [90].

Growing interest in understanding students' initial conceptions has led to the emergence of the field of conceptual change. To date, several researchers have developed theoretical models that attempt to describe the conceptual change process, which, according to Duit and Treagust [35, p. 673], "denotes learning pathways from students' pre-instructional conceptions to the science concepts to be learned". However, there are several theoretical differences between the various models of conceptual change. The differences concern the processes underlying conceptual change [24,27,32,33], and especially what happens to students' initial conceptions after undergoing conceptual change [8,71].

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[*] Corresponding author. Tel.: +1 514 755 3507; fax: +1 514 987 4833.
E-mail address: brault-foisy.lorie-marlene@uqam.ca (L.-M. Brault Foisy).

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Among the best known models of conceptual change, some authors describe conceptual change as an accomodation in which students' misconceptions are either replaced by the scientific framework [68] or substantially reorganized [70]. For Vosniadou et al.[88, p. 384], conceptual change is "a process that requires the significant reorganization of existing knowledge structures and not just their enrichment". Implicit to this postulate that conceptual change requires significantly reorganizing existing knowledge, there is the idea that students' prior knowledge no longer exists after a conceptual change occurs [76].

diSessa [31,32,34] presents a model of conceptual change called "knowledge in pieces" in which the learner's knowledge is divided into several units. According to this vision, the pieces can be organized or reorganized in different ways depending of the context. "Knowledge in pieces explains […] why change is difficult. Elements need to be re-contextualized, not erased, and many coordinated changes are necessary to create normative scientific concepts" [33, p. 44]. This idea suggests that initial conceptions do not disappear or are not abandonned during a conceptual change.

Similarly, Stavy and Tirosh [81] proposed a model according to which misconceptions would be the result of using intuitive rules. These intuitive rules would be seen as self-evident by the students and would lead them to generalize their use as opposed to other types of reasoning. Stavy and colleagues therefore claimed that many common incorrect responses in mathematics and science "can be interpreted as evolving from a small number of intuitive rules, which are activated by specific external task features" [80, p. 418]. For example, the intuitive rule *More A —More B* can lead to accurate conclusions in many common or scientific situations but can also lead, in other contexts, to wrong conclusions such as "larger area—larger perimeter" in mathematics [79]. Like diSessa's model, the intuitive rules model [81] suggests that what causes misconceptions does not disappear after a conceptual change occurs; they rather emerge when intuitive rules are used in inappropriate contexts.

Finally, other researchers argue that scientific concepts would rather act like a mask that covers students' initial conceptions than replace them [76]. According to these researchers, initial conceptions would therefore keep coexisting with scientific knowledge following improved conceptual performance [8,36,65,69,76–78]. In this perspective, they would remain accessible and available to students and could even be recalled in certain contexts. For example, Ohlsson [69] proposed a model (the resubsumption theory) in which two alternative conceptions can coexist. In this model, the selection of one conception over another would take place at a stage he calls "competitive evaluation", in which the conception that has the greater cognitive utility in the context of a given situation is chosen. From this point of view, conceptual change would be a cumulative process.

In light of this portrait, two main trends seem to emerge from the different models proposed by the scientific community. The first one is that initial conceptions are radically transformed or replaced, and no longer exist after a conceptual change. The second is that initial conceptions are still present after a conceptual change and therefore coexist with new scientific knowledge.

These two trends regarding students' initial conceptions have different educational implications. Indeed, teachers who want to remove or modify students' initial conceptions are not likely to teach the same way or use the same teaching strategies as teachers who want to help the students acquire a new scientific conception by teaching them to control or inhibit their spontaneous tendency to use their initial explanations. For instance, in a recent article proposing guidelines for improving classical models of conceptual change, Potvin [71, p. 27] argues that the idea of coexistence of conceptions implies that, from a pedagogical point of view, "forgetting seems to be unlikely, and expertise and 'conceptual change' appear to be more about making appropriate intuitions prevail than having the non-scientific ones altered", an idea he refers to as prevalence. From this perspective, a science teacher's goal would be to increase the status of inclinations that lead to scientifically correct answers or reasoning rather than to alter the student's initial conceptions. In order to guide instructional strategies more effectively, it thus becomes important to get a better understanding of the coexistence idea by examining the possible mechanisms accounting for this coexistence, that is, the mechanisms that allow to suppress a misconception in favor of a scientific conception.

Recent behavioral studies support the hypothesis that initial and scientific conceptions coexist. A study by Lombrozo, Kelemen and Zaitchik [55] found that patients with Alzheimer's disease (a condition known to impair and decrease executive functions such as the inhibition capacity) reverted to naive explanations when asked to interpret several natural phenomena. Likewise, Alzheimer's patients tended to revert to animist thinking when asked to judge whether things are living or not [91]. Other researchers found that naive conceptions about solids and liquids [4] and living things would persist during adolescence [6]. Despite an education in biology, adolescents still had difficulty classifying moving objects, like a car or celestial body, as living or nonliving, in comparison with static or inanimate objects. These studies suggest that learning did not eradicate the initial and naive explanations that the participants probably had when they were children. In fact, reminiscent of young children's beliefs, their explanations would continue to interfere in their ability to make decisions when their ability to inhibit is hindered because the requested task involves a strong naive conception, such as the one linking living objects to mobility.

Furthermore, other studies using reaction times have shown that healthy participants would also have a tendency to endorse naive explanations when their capacity to inhibit their initial intuitions is impaired by processing demands such as a context of speeded response. Undergraduate students [47] and even professional scientists [48] tended to evaluate teleological explanations of natural phenomena as correct when given less time to answer the question. Moreover, it also seems that even when an accurate answer is given, there are still conflicts between naive and scientific conceptions. In a recent study [76], adults with many years of science education were asked to judge, as quickly as possible, the accuracy of two types of scientific statements (intuitive and counterintuitive) across 10 domains of knowledge. The results indicate that for strongly counterintuitive statements (for which a common misconception is presumed to interfere with the scientific answer), the participants answered with less accuracy and significantly slower, even when they answered correctly. According to these researchers, this higher reaction time would indicate that, for counterintuitive statements, the participants would need to exert greater cognitive effort because they would have to suppress or inhibit their initial intuition in order to answer correctly. These authors argue that scientific conceptions would not overwrite but rather suppress the initial ones and, according to their results, the resilience of early intuitions would have implications in many scientific domains of knowledge.

While these results provide additional insight into conceptual change, especially regarding what happens to initial conceptions after change occurs, the link between conceptual change and inhibition remains rather indirect since it was mainly measured through reaction times. It is widely accepted that the time it takes to respond is a good indication of the complexity of the reasoning involved in a cognitive task [79]. Nonetheless, the link between longer response times and inhibition is more difficult to establish as it depends critically on the quality of the stimuli used in the task and the control of factors such as the familiarity, complexity, and analysis level of the stimuli [72]. Another possibility is to examine inhibition and science learning through neuropsychological tests. Some studies investigated the possible correlation between the development of inhibition and conceptual change in science. It appears that the capacity to inhibit is correlated with conceptual