PATRICE POTVIN, STEVE MASSON, STÉPHANIE LAFORTUNE
and GUILLAUME CYR

PERSISTENCE OF THE INTUITIVE CONCEPTION THAT HEAVIER OBJECTS SINK MORE: A REACTION TIME STUDY WITH DIFFERENT LEVELS OF INTERFERENCE

Received: 5 April 2013; Accepted: 30 January 2014

ABSTRACT. Recent research efforts have argued for the *persistence* of some of students' frequent scientific misconceptions, even after correct answers are produced. Some of these studies, based on the analysis of reaction times, have recorded latencies for counter-intuitive or incongruent stimuli compared to intuitive or congruent ones. The proposed interpretations were that prior knowledge survives learning and still coexists with new closer-to-scientific knowledge, producing conflicts that delay correct answers. But these conclusions are based on the assumption that stimuli from different conditions only differ in the presence/absence of interfering misconceptions, which is sometimes, in our opinion, a rather fragile claim. Thus, we have designed a task in which it is possible to test different levels of interference and not only its effects in contrast to another condition. Then, we have used it to see if different intensities of interference produce different levels of conflict. The task tested the persistence of the misconception that "heavy objects sink more than lighter ones". One hundred twenty-eight 14- to 15-year-olds were asked to tell which of the 2 balls presented (3 different materials and 3 different sizes) would "sink more" than the other. Analysis verified the presence of latencies and negative priming. For the most part, results show that the intensity of interference does produce corresponding latencies, which suggests greater conflict and therefore supports the hypothesis of persistence and coexistence of conceptions, even after correct answers are produced, and beyond other plausible effects due to the used stimuli. Prescriptions for theory and teaching are proposed.

KEY WORDS: buoyancy (sink/float), conceptual change, misconception, negative priming, persistence, reaction time, science education

Context

Considerable efforts have been made since the 1970s to address the problem of the initial and naïve ideas, sometimes called "misconceptions", which students bring to science classes and that are known to often interfere with teaching. To better understand the history of the research that has been conducted in the "conceptual change" field, we refer the reader to DiSessa (2006) and to other very accessible and complete syntheses that have been proposed (Duit & Treagust, 2003, 2012).

Most of the conceptual change models that have been proposed in this very fertile field are based on the assumption that "if conceptual *change* succeeds, then initial conceptions cannot be left intact. They have to be, according to the concept of change, either completely abandoned, modified, replaced, reorganized, eliminated, rejected, transformed, or restructured." (Potvin, 2013, p. 5). This research, like other recent psychological and neuroscientific studies, will challenge this view of conceptual change.

Indeed, in recent years, a growing number of studies have argued that many frequent non-scientific conceptions (sometimes designated as "misconceptions") will not vanish or be recycled during learning, but will on the contrary *survive* or *persist* in learners' minds even though these learners eventually become able to produce scientifically correct answers. Shtulman & Valcarel (2012), for example, measured the reaction times of 150 college undergraduates who were asked to judge if scientific and unscientific sentences, taken from 10 domains of science and mathematics, were true or false. Some of these statements were labelled as "consistent" when they were usually both true or false both from the novice's and expert's standpoints (e.g. "rocks are composed of matter"; "numbers are composed of matter") and "inconsistent" when they were more frequently false according to experts, but frequently true for novices or vice versa (e.g. "fire is composed of matter"; "air is composed of matter"). Results for correct answers showed that "participants were significantly slower at verifying inconsistent statements than at verifying consistent ones, both across domains [. . .] and within domains [. . .]" (Shtulman & Valcarel, 2012, p. 212). Results were robust to differences in true-falseness of statements. Also, these authors argued that results could neither be attributed to differences in the syntactical or linguistic forms of the sentences nor to the level of familiarity with the information given. It was therefore suggested that if some correct answers required more time to be produced than others, it was most likely because they required more demanding cognitive processes. Since differences in reaction times matched conditions that differed in the involvement of common misconceptions, lags were attributed to the suppression of these conceptions.

Results that support this interpretation were obtained by Babai & Amsterdamer (2008) in conceptions about solids and liquids and by Babai, Sekal & Stavy (2010) about living things. The former research involved images of rigid, non-rigid or powder solids and of runny or dense liquids that had to be correctly classified as "solids" or "liquids". Since naive conceptions about liquids and solids often unduly involve some directly perceptible properties, like “pourability” or “hardness”, the correct qualification or disqualification of some of the represented substances was presumed to be less intuitive, as in the case of Plasticine or honey. Indeed, reaction times confirmed that “reasoning processes associated with correct classification of objects that are not consistent with the naive conceptions are more demanding” (Babai et al., 2010, pp. 556–557), and they therefore argued that “naive conceptions in young children persist and affect junior high school students” (Babai et al., 2010, p. 557). The second study also used images. Pictures of living and non-living things were presented to 15- to 16-year-olds. Some of these stimuli were considered as “intuitive” (insects, mammals, static objects) and others as “less intuitive” (flowers, celestial bodies, vehicles) because of the naive idea that living objects usually move. Since correctly classifying plants took longer than classifying animals and that classifying dynamic non-living objects took longer than classifying static ones, the authors argued that “despite prior learning in biology, the intuitive conception of living things persists up to 15 to 16 years of age, affecting related reasoning processes”.

Reaction times to a buoyancy task were also studied by Lafortune, Masson, & Potvin (2012a) in a developmental study. These authors concluded that inhibition is most likely involved in the explanation of the improvement of answers as children grow older (ages 8 – 14). Other studies that considered accuracy, reaction times or fMRI data were led by Houdé (2000); Houdé, Pineau, Leroux, Poirel, Perchey, Lanoë et al. (2011); Houdé, Zago, Mellet, Moutier, Pineau, Mazoyer et al. (2000); Dunbar, Fugelsang & Stein (2007); Rossi, Lubin, Lanoë & Pineau (2012); Lubin, Lanoë, Pineau & Rossi (2012); Potvin, Turmel & Masson (2014); Masson, Potvin, Riopel & Brault-Foisy (2014); Kelemen & Rosset (2009) and Kelemen, Rottman & Seston (2012). These authors have concluded that inhibition could play an important role in the production of correct answers when anterior knowledge could potentially interfere. The idea that there is a role for the function of inhibition in the production of correct answers is, in our opinion, consistent with the idea of persistence of misconceptions because it necessarily raises the question of what it is that is inhibited. Even though evidence for the persistence of misconceptions and the role of inhibition is growing with convincing results, we believe that doubt still exists about the equivalence of difficulty or familiarity of some of the previously described stimuli that have been used in some previous research to support the claim of persistence.

Researchers have made a great deal of effort to design tasks where congruent/incongruent and intuitive/counter-intuitive contrasts are based only on the difference between the presence and absence of interference of previous knowledge. For instance, they calculated reaction time differences between very similar images (Babai & Amsterdamer, 2008) or syntactically similar sentences (Shtulman & Valcarel, 2012) that differed only in configuration or in content. These efforts are crucial for the persistence claim because demonstrations of interference of previous knowledge depend on the acknowledgement that delays in answers cannot be attributed to other causes.

Providing Convincing Evidence for the Persistence Claim

As Shtulman & Valcarel (2012, p. 213) suggested, however, it is possible to argue that differences in content might sometimes involve differences in familiarity with these content elements and therefore explain certain differences in reaction times that were recorded. Following this line of thought, we believe that differences in the nature of the content might also cause differences in the complexity of the thinking processes that need to be engaged to produce correct answers.

For instance, qualifying "bacteria turn food into energy" as true and "plants turn food into energy" as false might take more time than qualifying "people turn food into energy" as true and "rocks turn food into energy" as false (Shtulman & Valcarel 2012, p. 211). However, this difference might not be due to the presence/absence of conceptual interference, but rather to familiarity. Indeed, in order to answer correctly, one simply needs to know that humans have to "eat" (put in stomach or intestine) the same kind of "food" everyone finds in their refrigerator every day in order to obtain energy and survive. What constitutes "food" for a plant or a bacterium, on the contrary, is clearly less familiar. It involves some invisible complex organic molecules that we might not even be able to distinguish from other molecules if we could see them. Even from an expert's standpoint, "bacteria turns food into energy" and "plants turn food into energy" have more of an analogical status that they are scientific statements and therefore might require more time to answer correctly. Therefore, what is "food" from a vitalist theory vs. a "psychological theory of bodily functions" might not only be resistance to a vitalist theory but also a question of proximity.

Answering these last two stimuli ("bacteria" and "plant") correctly also requires that we take the problem to the microscopic level. The "human" and "rock" problems do not require this. Understanding that bacteria absorb and process "food" (organic molecules) into energy (adenosine triphosphate) within mitochondria is, in our opinion, more complex (and less familiar than many other concepts) than simply knowing that if humans do not eat, they will die, or that rocks do not require food because they are not alive. Bacteria have very complex biochemical active exchanges with their environments and within themselves; humans have exchanges that are simpler to conceive (food and oxygen go in and carbon dioxide and faeces go out). Again, we believe that lags can be attributed not to differences in conceptions, but this time to the complexity of the path that leads to the correct answer. The "plant" problem appears to be even more complex because plant cells not only transform organic molecules (sugars) into energy but also produce the sugars they use through photosynthesis. Therefore, knowing that "plants do not turn food into energy" (which is the correct answer to the question, according to the authors) becomes a "balance sheet" problem, which can, we believe, explain why it takes more time to answer than an unidirectional problem like "bacteria/people turn food into energy" would. Although sometimes simpler, like Ockham's razor suggests, scientific knowledge is in some cases just heavier to handle than naive knowledge.

Finally, we believe that sometimes comparing the reaction times of stimuli that involve various content elements can involve too many unexpected conceptions. In the "people/rocks/plants/bacteria turn food into energy" example, we believe that much more than one misconception could be involved, such as "rocks are living things", "plants (or bacteria) do not need energy" or "are not alive because they are not (or are less) mobile" and "living things do not produce their own food". For some stimuli, delays could be attributed to the presence of a sum of conceptions, instead of the presence/absence of only one of them. Interesting interpretations can be drawn from such designs, but thorough discussions about the influence of every conception have to be conducted.

Even if we believe that it is possible to argue for the equivalency of complexity of many of the stimuli used in previously presented studies, it remains that these interpretations are merely based on the analysis of the stimuli themselves, and not on the cognitive processes they possibly can or do trigger. Even if the authors strongly argue that "the two task conditions are logically identical and require the same logical operations" (Babai, Eidelman & Stavy, 2012, p. 772) or that "consistent and inconsistent statements do not differ, after all, in the complexity of their linguistic form" (Shtulman & Valcarel, 2012, p. 213), the human spirit and natural inclinations still remain black boxes, and processes that are triggered by closely related—but still different—stimuli remain unknown for the moment. Human behaviour is sometimes unpredictable and sensitive to all sorts of unexpected influences. To presume or predict its behaviour and use these predictions as arguments might in some cases be unwarranted.

We believe this problem has to be addressed for the purpose of the credibility of the persistence claim. A considerable amount of efforts in this direction has already been made, but we believe that it is also important to go beyond arguments according to which structurally similar stimuli should always be presumed as being of equal difficulty.

For this purpose, we propose to test differences in conceptual interferences with a task that builds on the qualities of the ones used in the previously described studies but that also avoids the possible biases discussed above. All stimuli, including intuitive and counter-intuitive, will therefore (1) have a similar structure (configuration), (2) involve the same conceptual interference, (3) ask the same question and (4) not involve differences in content, therefore avoiding familiarity and complexity biases. Furthermore, our task will avoid possible biases due to the use of different fingers or hands and biases due to use of "correct/incorrect" choices, which can trigger unequal thinking processes.

In order to confirm that there is no discontinuity between our two intuitive and counter-intuitive conditions, we will also analyse the effect of *different levels* of interference. Instead of using stimuli that test differences of *content* on reaction times, we suggest using stimuli that test differences in the *intensity* of the conceptual/intuitive interference on reaction times. We mean by "intensity of interference" that some case examples, although they test the same conception, might nevertheless present differences in magnitude. For example, to be tested on the misconception according to which "higher pitch sounds travel farther" (Thouin, 2001), one could be subjected to a task that includes hearing different levels and pitches of sound.

The hypothesis of this research is thus that differences in the intensity of interference will produce proportional differences in reaction times. If this hypothesis is confirmed, we believe it will support the credibility of the hypothesis of the persistence of misconceptions, at least for the tested domain and participants, and that it will echo with previous research about persistence.

Negative Priming as an Additional Indication of Inhibition

Finally, another growing argument that inhibition might be involved in the production of some correct answers is based on negative priming studies. Negative priming is recorded latency that occurs when a trial (probe) is immediately preceded by a trial (prime) in which a distractor (like a misconception) has to be actively ignored. "When primes received intentional processing, they facilitated processing of identical probes; when the same primes were (actively) ignored, processing of subsequent probes was delayed (negative priming)" (Tipper, 1985, p. 586). Even though some alternative causal explanations for such latencies—sometimes based on memory retrieval—have been proposed (Egner & Hirsch, 2005), most of the authors attribute the phenomenon to the presence of the function of inhibition (Borst, Poirel, Pineau & Cassoti, 2012; Tipper, 2001). For example, using a task where an intuitive interference (misconception) according to which “the shape with the larger area has a larger perimeter”, Babai et al. (2012) tested 51 11th and 12th graders to “explore whether correctly answering an incongruent condition prime in the first part of the task would increase the response time of a subsequent congruent probe trial” (pp. 766−767). Their analyses of correct answers led them to conclude that “pre-activation of control mechanisms (inhibition of intuitive interference on an earlier problem) can interfere with a subsequent problem that is in line with intuitive reasoning”. Therefore, since negative priming has in many cases been considered as an indication of the presence of inhibition, we will also investigate for this phenomenon in order to provide stronger evidence for the claim of persistence.

Method

Participants

One hundred twenty-eight 14- to 15-year-old participants from three secondary schools in the greater Montreal area were involved. These subjects had previously been taught concepts about floating objects at the elementary level and in their first years at the secondary level. We chose to involve 14- to 15-year-olds because we knew, from Lafortune, Masson, & Potvin (2012b) work, that at this age, students very frequently produce correct answers about floating objects and still show different reaction times for intuitive/counter-intuitive stimuli. Five subjects that achieved near to 50 % accuracy were excluded from the analysis because their scores suggested that they did not take the test seriously. All other subjects scored above 65 % accuracy, and the majority of them were above 90 %. Mean accuracy for this task is 88 %, which is generally in line with previous results for students about this age (Lafortune et al., 2012a)

Materials

We designed a task that involved the misconception that the mass of an object is the cause of its floating/sinking behaviour. It is a misconception because floatability does not depend on mass alone, but rather on a specific density, which is a characteristic property of different substances. Therefore, an object made of lead will always have a stronger tendency to sink than, for example, another object made of wood, regardless of the mass or size of each one.

The difficulties in understanding why objects have more or less strong tendencies to sink or float have been thoroughly studied for quite a long time (Hewson, 2006; Hsin & Wu, 2011; Piaget & Cook, 1952; Smith, Carey & Wiser, 1997), and many explanations for these difficulties have been proposed. Some of them suggest confusion between mass, volume, weight and density (Rowell & Dawson, 1977; Smith, Carey & Wiser, 1985, 1992), and others suggest that the depth of liquid or the presence of air within the floating objects plays a role. In his misconception directory, Thouin argues that the statement "light objects float and heavy objects sink" (Thouin, 2001, p. 37) is a "frequent conception". Inspired by Posner's conceptual change model (Posner, Strike, Hewson & Gertzog, 1982), many authors have proposed ways to tackle this difficulty (Potvin, 2011). However, we believe that one of the most fertile and operational explanations for the misconception that links buoyancy to mass is formulated by Yeend, Loverude & Gonzales (2001, p. 4).

> Many student responses show a consistent pattern of associating each of the quantities mass, volume, and density with size. These responses can be interpreted as illustrating an inability to distinguish between these related concepts. An alternative interpretation is based on the work of Stavy & Tirosh (2000), who assert that many students answer questions in mathematics and science by appealing to intuitive rules: the rule 'More A–More B' is the common core to many reported apparent misconceptions.

We have also chosen to study this particular conception (float/sink) because sizes and substances can easily be represented through images and, afterward, easily and quickly recognized. Also, the size of objects can easily be modulated and quickly recognized as bigger/smaller than others. In such comparative problems, the conception that "light objects float and heavy objects sink" is translated into "the more an object is heavy (big), the more it sinks". Therefore, different weights can easily be represented by different sizes of balls in a trial that asks "which of these two objects will sink more than the other?"

Drawing on the task developed by Potvin (2013), we used images involving three types of materials [lead, wood and polystyrene (synthetic foam material)] that were usually familiar to students and three sizes of balls (small, medium, big). We then designed all possible combinations of stimuli with these sizes and materials and excluded the ones for which there was no possible correct answer (e.g. two wooden balls of different sizes). Instead of limiting ourselves to the typical "intuitive/counter-intuitive" binary and dichotomous design, where the misconception is presumed to either support or spoil the production of correct answers, we added a "neutral" level of interference. In that particular level, the mass of the ball is supposed to not interfere in resolution (two balls of the same size). We also added a "very counter-intuitive" level, where the difference in mass is higher (two degrees of difference in size, e.g. small/big) than in the "counter-intuitive" level (one degree of size, e.g. small/medium or big/medium). Finally, we added a "very intuitive" level, where the difference in mass is also higher (two degrees of size) than in the "intuitive" level (difference of one degree of size). Thus, we had five subcategories of stimuli (Fig. 1).

Procedure

Every participant was presented with the sinking/floating ball task on a personal computer. At the beginning of the session, each of them was

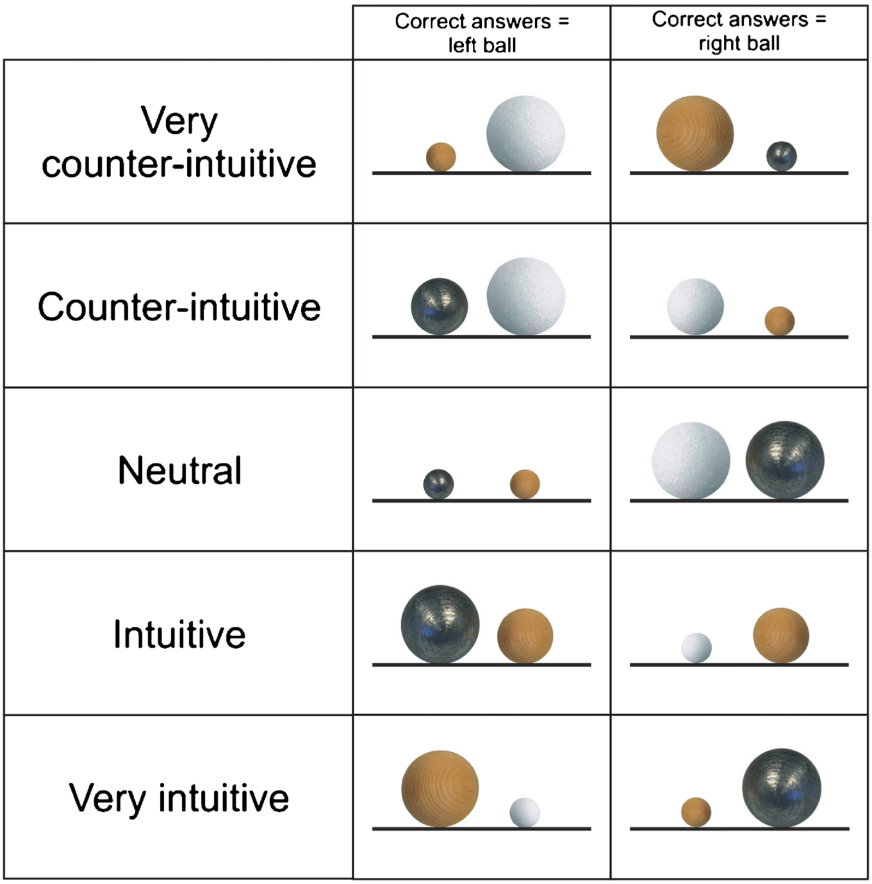

Figure 1. Examples of stimuli for the five levels of interference (conditions) and the two possibilities of correct answers (*left*/*right*)

presented with instructional slides. Then they were asked to tell for every trial if the left or right ball was the one that "will have the strongest tendency to sink if it were put in a water tank"—"tendency to sink" means here that the object would at the end be closer to the bottom of the imaginary tank in which the objects would be plunged. The 54 different images (18 "intuitive" (including six "very intuitive"), 18 "counter-intuitive" (including six "very counter-intuitive") and 18 "neutral") were presented in a random order four times to each of the students, for a total of 216 stimuli, with each sequence separated by a short pause. There was a fixation (black "+" sign) of 400 ms between each stimulus, and a maximum delay of 5,000 ms was allowed to produce answers. Participants were asked to give answers as quickly as they could, although it was indicated as more important to give correct answers than fast ones. Participants had to answer by pushing keys 1 and 2 (left ball and right ball, respectively) on the keyboard. There were an equal number of right and left correct answers so that usual biases due to the use of particular fingers or hands (Aoki, Francis & Kinoshita, 2003) were compensated. For each presented stimulus, the E-Prime™ software recorded the order of presentation, accuracy and reaction times.

Analysis

To verify our hypothesis, the mean reaction time for each participant for each category of stimuli was determined and used to perform paired *t* tests between the three main categories ("intuitive", "neutral" and "counter-intuitive") and between all subcategories (three main categories + "very intuitive" and "very counter-intuitive").

In order to check for negative priming and in accordance with the "prime-probe paradigm" (Babai et al., 2012, p. 766), we divided each of the three main categories into three types: (1) "immediately preceded by intuitive", (2) "immediately preceded by neutral" and (3) "immediately preceded by counter-intuitive". Less data was considered for this last analysis because to be considered, a trial had to be not only answered correctly (probe) but the precedent trial (prime) also had to be answered correctly, which is more restrictive. ANOVAs and *t* tests were carried out for every combination within the categories.

Results

All of the following figures show response times (small diamonds) for answers, along with the 95 % confidence intervals surrounding them. All of the following analyses were obtained by using the means, paired *t* test and ANOVA functions of the SPSS™ software. Mean accuracy was about 88 % throughout the task, and only correct answers were analysed. Effect sizes (ES) are given when applicable and according to Schroeder's recommendations (Schroeder et al., 2007).

Main Categories

Figure 2 indicates response times for the three main categories of the task. Differences between every set of two categories were significant ["Intuitive" vs. "counter-intuitive": $t(121) = -8.054$, $p < 0.001$ (ES = 0.40); "neutral" vs. "counter-intuitive": $t(121) = 4.376$ (ES = 0.19), $p < 0.001$; "neutral" vs. "intuitive": $t(121) = -4.108$, $p < 0.001$ (ES = 0.2)]. Since our "neutral" condition is in the intermediary position between intuitive and counter-intuitive reaction times, it is possible to see, with the use of these three levels, that differences in the intensity of the interference can induce proportional latencies and therefore possibly proportional conflict.

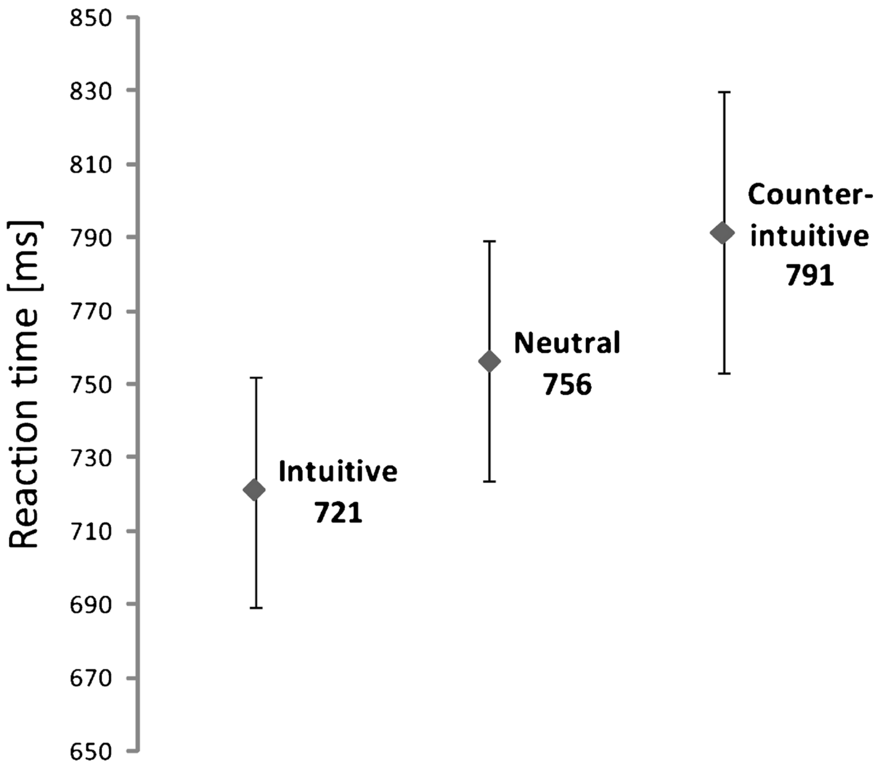

Figure 2. Reaction times for the three main categories of stimuli

Subcategories

Figure 3 reports response times for the five subcategories of the task. It shows that, in our task, the more significant the difference in size of the balls, the more strongly it interacts with knowledge (either in the same direction as knowledge or in the opposite direction). The differences between "neutral" and "intuitive" trials (this time excluding the "very intuitive" trials) were found to be significant: ($t(123) = -16.42$, $p < 0.001$) (ES = 0.17) as were the differences between "neutral" and "counter-intuitive", this time excluding the "very counter-intuitive" trials ($t(123) = -4.995$, $p = 0.017$) (ES = 0.15). However, even if the "very intuitive" category also had significant differences with all other subcategories, we were not able to show that the difference between "very intuitive" and "intuitive" is significant ($t(123) = -0.727$, $p = 0.469$). The same can be said about the difference between "very counter-intuitive" and "counter-intuitive" ($t(123) = -1.037$, $p = 0.303$).

Negative Priming

In order to show the presence of negative priming, we present three graphics (Figs. 4, 5 and 6) in which reaction times of every category are

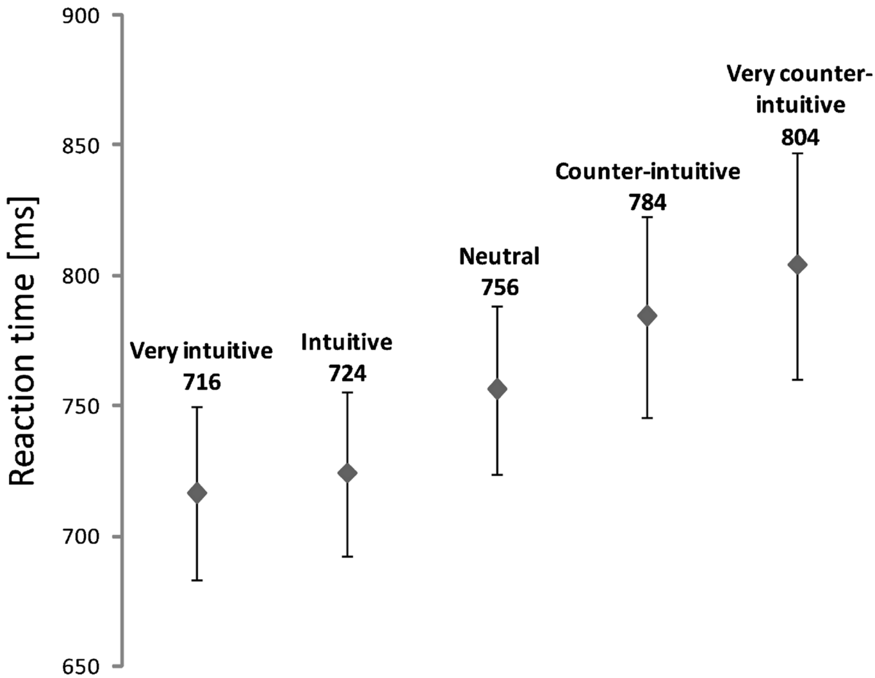

Figure 3. Reaction times for the five subcategories of stimuli

split between three types according to the category to which the immediately preceding trial belonged to. Figure 4 indicates reaction times for the three types of intuitive stimuli. Consistent with the definition of negative priming, the data shows that reaction times are longer if the previous trial engages a different cognitive process. A one-way, between-trials ANOVA was conducted to compare reaction times between "immediately preceded by" (1) "intuitive", (2) "neutral" and (3) "counter-intuitive" conditions. There was a significant effect at the $p < 0.05$ level for the three conditions [$F(2, 7{,}469) = 11.307$, $p < 0.001$]. What is interesting about this particular result is that the impairment appears to depend on the intensity of the interference. Indeed, reaction times following neutral stimuli show less impairment than following counter-intuitive ones; differences between "preceded by intuitive" and "preceded by counter-intuitive" ($t(121) = -4{,}169$, $p < 0.001$) and between "preceded by neutral" and "preceded by counter-intuitive" ($t(121) = -3{,}353$, $p = 0.001$) are highly significant, although we were not able to show significant differences between "preceded by neutral" and "preceded by intuitive".

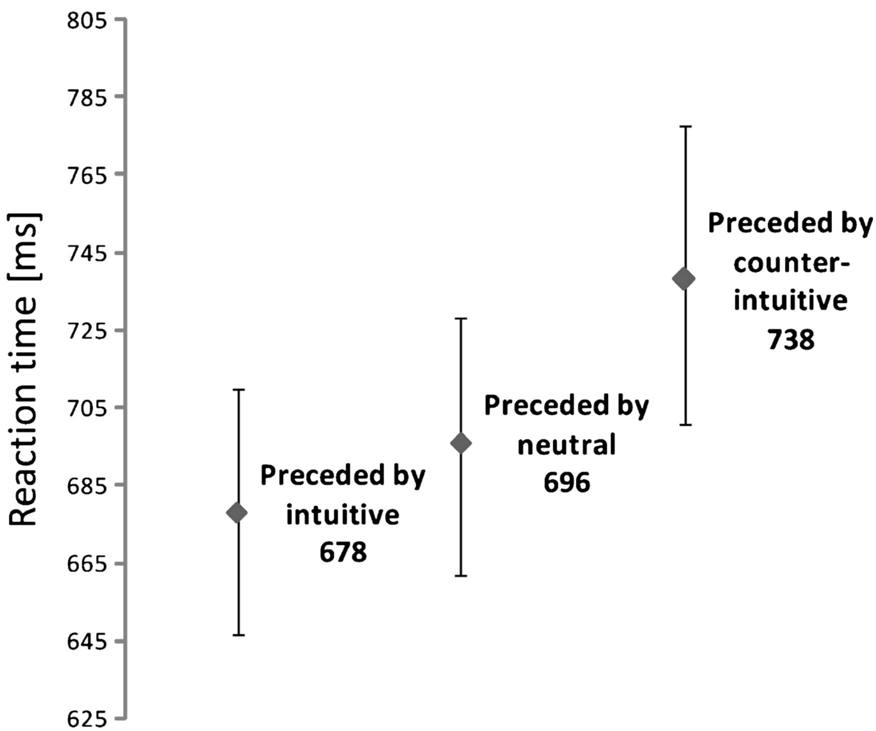

Figure 4. Reaction times for the three types of intuitive stimuli

Figure 5 gives response times for the three types of neutral stimuli. In this case, it was not possible to significantly show the presence of any negative priming, either with ANOVA or individual *t* tests on different combinations. Although it could be imprudent to draw conclusions from the absence of significant results, it still can be suggested here that since neutral stimuli presumably do not involve inhibition, then it could be normal that lags are harder to see.

As in Fig. 4, Fig. 6 shows that reaction times are longer if the previous trial engages a different cognitive process. But this analysis is—again—mainly interesting because it shows that this lag seems to depend on the intensity of the interference.

Indeed, reaction times following neutral stimuli show less impairment than when following intuitive ones; the difference between "preceded by intuitive" and "preceded by counter-intuitive" is significant ($t(121) = 2.123$, $p = 0.036$), whereas the difference between "preceded by neutral" and "preceded by intuitive" ($t(121) = 1.721$, $p = 0.088$) is close to significant levels. However, we were not able to show significant

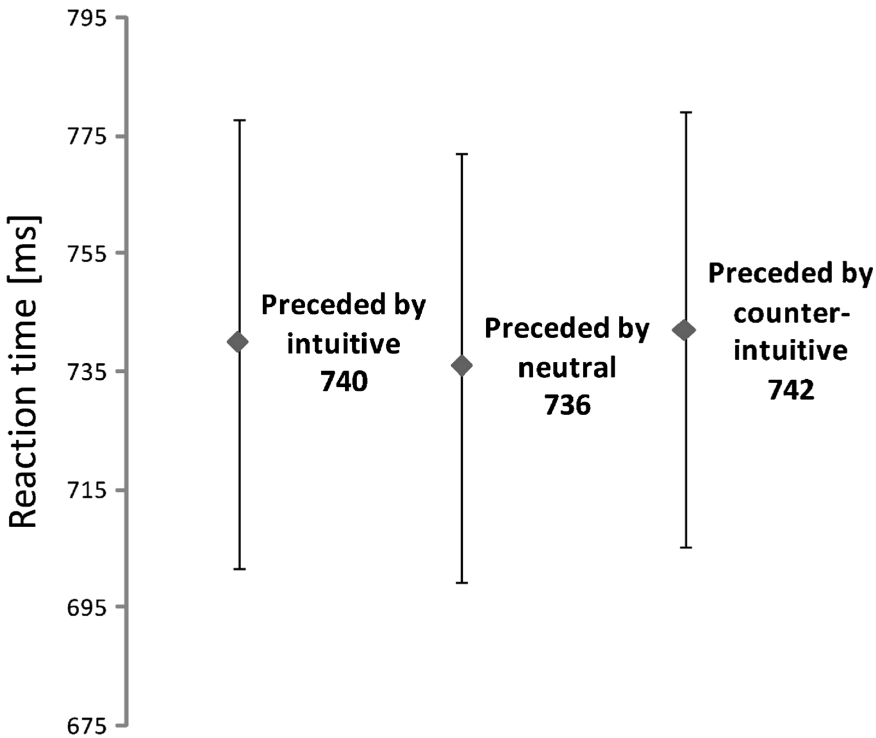

Figure 5. Reaction times for the three types of neutral stimuli

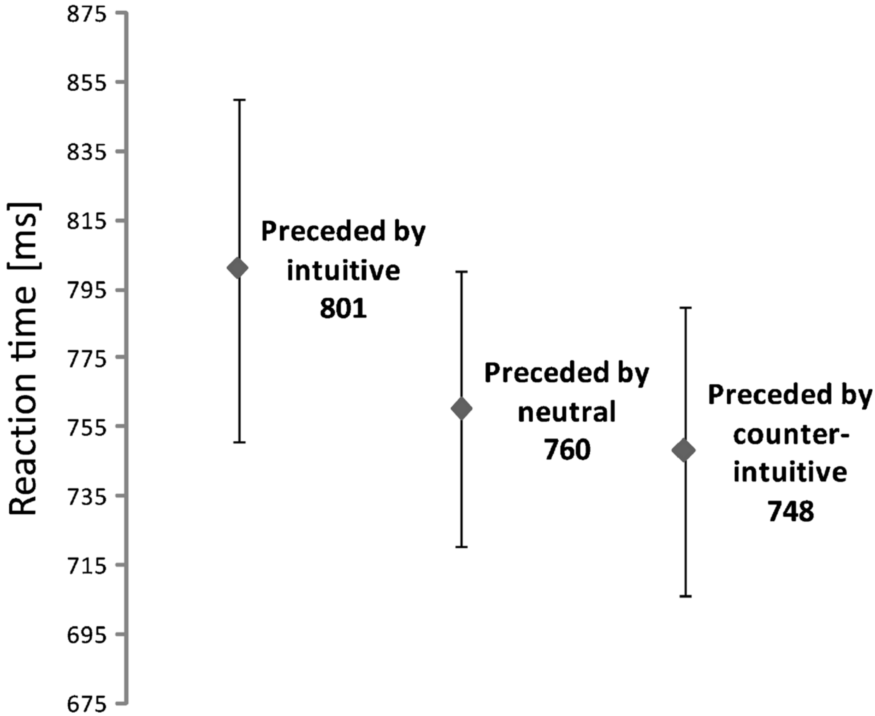

Figure 6. Reaction times for the three types of counter-intuitive stimuli

differences between "preceded by neutral" and "preceded by counter-intuitive".

Discussion

Contribution to Research

When students become able to produce scientifically correct answers about floating/sinking objects, what happens to their initial conceptions or intuitions (like the conception that heavier objects have a stronger tendency to sink than lighter ones)? Our findings suggest that conceptions or intuitions continue to exist in the decision-making process (Masson et al., 2014) that leads to correct answers, not only because of the latencies in responses where these conceptions/intuitions interfere negatively (they "spoil" reaction times, compared to neutral stimuli) but also because of accelerations in responses where the same conceptions/intuitions interfere positively (they "coincide" with correct answers and speed up reaction times, compared to neutral stimuli). Since our data goes beyond classic dichotomous designs (with merely intuitive and counter-intuitive stimuli) and uses more than one levels of interference, we believe that it suggests at least a partial verification of the hypothesis, and because some of its parts (the extremes) have not shown to be statistically significant, we also believe that further verification could be welcome. Indeed, it is possible that complete verification could not be achieved because we did not test enough participants, or that differences in sizes of the presented objects were not substantial enough to produce measurable differences on reaction times. Also, it is not impossible that ball sizes simply do not affect reaction times at all, but since our data does not point in this direction [conditions are all in ascending order, according to the hypothesis (see Fig. 3)], we rather are optimistic.

Nevertheless, the use of more than two levels of interference, combined with the observed continuity in reaction times between "very intuitive" and "very counter-intuitive" stimuli (passing through "neutral"), brings strength to the hypothesis that all of our stimuli were about interference due to the same conception and that they differed essentially in magnitude. In a dichotomous design, the only possible interpretation to the observed differences in reaction times would have led to a confirmation of the existence of a difference in activated processes, but without proof that both of them were about mobilization of the same cognitive process or the same conception.

We believe our results are consistent with past similar studies using reaction time designs for the study of conceptions in other domains of science and technology. In these, initial conceptions/intuitions have been shown to "persist and affect junior high school students" (Babai & Amsterdamer, 2008, p. 557), to "be suppressed but not supplanted" (Shtulman & Valcarel, 2012, p. 213) by scientific knowledge, and that thought processes continue "to be influenced by these intuitive conceptions" (Babai et al., 2010, p. 24). We believe that our research supports these interpretations because it argues that intuitive interference not only influences reaction times because of its particular nature but also through its intensity. We also believe that these "proportional" latencies can be expected to reveal conflicts or competitions between conceptions, or, as it has been argued before, between distinct types of processes, such as experience-based or rule-based processes (Evans, 2003). Indeed, if we acknowledge, for certain contexts, the possibility of the coexistence of conceptions/intuitions and the need to produce only one answer, then the logical conclusion is that there must be a prevalence (Potvin, 2013) and maybe also an inhibition (Houdé et al., 2011) of certain ideas in order to succeed at the task. This interpretation of our results is at least partially inconsistent with some views of conceptual change.

Although proposing a definitive classification of conceptual change models could be risky, it appears quite safe to say that there are multiple perspectives within this research field. Among them, many could be associated with the idea that when conceptual change occurs, initial conceptions …

> …cannot be left intact. They have to be, according to the concept of change, either completely abandoned (Villani, 1992), replaced (Posner et al., 1982, p. 212), reorganized (Jensen & Finley, 1995, p. 149), eliminated (Nersessian, 1998), rejected (Hewson, 1981, p. 385), transformed or 'restructure[d]' (Limon, 2001, p. 359). (Potvin, 2013, p. 5)

Ohlsson (2009) might call this category "transformation-of-previous-knowledge" (p.20), and many of the models that belong to it can also be associated to the "classical tradition" of conceptual change, where cognitive conflict is seen as an inevitable and preliminary step. We believe that the main contribution of our study is that it challenges some aspects of these models. Indeed, if initial conceptions survive learning, then the idea of "change", as it is understood in these models, might have to be reconsidered. Since modifications in the quality of answers appear to be possible, and if initial conceptions persist and coexist with new ones, then learning might be better explained in terms of "reversal of prevalence" then in terms of change (Potvin, 2013). This idea that conceptions, right or wrong, can coexist within a learner's mind is not new, though, and has been repeatedly suggested in the past by Solomon (1984), Chi (1992), Spada (1994) and many others, but maybe without being given enough attention. On the basis of our results, we suggest that more research efforts should from now on be made in this direction and that hypotheses about prevalence be tested. We also believe that the task we developed could inspire further research efforts that are not only interested in accurate responses but also in the level of prevalence of certain conceptions in certain contexts.

About Negative Priming

As in the previous study of Babai et al. (2012), our analysis of the negative priming effect suggests that a "different reasoning process is associated with each (congruent-incongruent) condition" (p. 772) and that these processes might therefore be "possibly localized in different brain areas" (Babai et al., 2012, p. 558). Our results indeed show that "previous trial congruity affects the response times" (p. 772) for both intuitive and counter-intuitive stimuli. What is original here is that we were able to show that neutral prime trials do not affect probes as much as intuitive or counter-intuitive ones, attesting the "vectorial" nature of interferences.

Babai et al. had already noticed that some of their sub-conditions were "more demanding" than others. We believe that the results of our five sub-conditions are in line with their interpretation.

Also, if we agree with Houdé & Guichart (2001) and Borst et al. (2012) that the presence of negative priming "supports the suggestion that inhibitory control mechanisms play a key role in overcoming intuitive interference" (p. 763), then we believe that our task, by showing the symmetrical and proportional presence of negative priming in Figs. 4 and 6, also supports this hypothesis. Indeed, the most important negative priming (53 and 60 ms) between types of stimuli was obtained in cases where counter-intuitive stimuli immediately preceded or followed intuitive ones (Figs. 4 and 6). On no occasion did neutral stimuli produce as much negative priming in probes (Figs. 4 and 6, middle points), and when neutral stimuli were used as primes, it became impossible for us to record any difference between types (Fig. 5). It can therefore be suggested that inhibition was engaged to overcome interferences and that the distractor to be ignored was the mass (size) of the ball. However, since negative priming obtained when primes are "intuitive" and probes are "counter-intuitive" is comparable to when the opposite happens, it raises the question of what could be considered the distractor in intuitive stimuli. Therefore, we believe that it could be possible to argue that negative priming was present in our experiment not only because of the presence of a distractor to inhibit but simply because intuitive and counter-intuitive stimuli engaged very different processes that necessitated switching from one mechanism to the other. This switching could be used to explain lags. It is also possible that lags in counter-intuitive probes that are preceded by intuitive primes could be explained by considering that the restarting of inhibition mechanisms takes time. This last interpretation could support the presence of inhibition. Facing this dilemma, we believe that further research is needed to enlighten this difficult problem. We also believe that further research that tests the incremental intuitive interferences associated with other fields or educational problems of science and technology could help confirm (or not) our interpretations that interference not only has an effect of a certain nature but that this interference has an intensity.

Educational Recommendations

Some educational recommendations could be made in light of our results. First, it appears that curriculum designers and teachers should be aware that increasingly credible indications that initial conceptions may persist even after correct answers make their appearance are being published these days. This might be an invitation to be skeptical towards transformation-of-knowledge models of conceptual change, as well as to increase vigilance for the recovery of initial unscientific answers. Indeed, if answers are the result of prevalent conceptions, this prevalence may be temporary. Therefore, special attention should be given to curricular designs that concentrate on ensuring durability of learning (or of prevalence).

Our results also suggest that if teachers feel the need to provoke conceptual conflicts in order to make themselves clear, to “capture imaginations” or to provoke more intense and possibly durable educational experiences, then they should probably not be afraid to overemphasize their examples or illustrations and evoke cases of striking differences, at least at the beginning of teaching sequences. Since greater intensity of interferences (like when a small lead ball is compared to a big polystyrene one) engaged more time-demanding processes and possibly greater cognitive conflict than smaller intensities, we can extrapolate and suggest that comparing the buoyancy of a giant tanker boat (that floats even though it weights thousands of tons) to that of a sewing needle would provoke a stronger conceptual conflict than, say, comparing a wooden ball with a slightly bigger lead ball.

“Knowing how difficult conceptual change can sometimes be, combined with knowing that conceptions often persist even after instruction, we believe our research informs educators of the crucial importance of good early instruction. The quote “Be very, very careful what you put in that head because you will never, ever get it out” by Thomas Wolsey (1471–1530) seems to be rather timely in this case, even though it was written long ago. Indeed, there is no need to go through the difficult process of “conceptual changes” if there is nothing to change”.

Finally, the consideration of a role for inhibition in the learning process of science suggests that if one improves one’s general capacity for inhibition, then it might facilitate the various conceptual changes one has to go through. Some promising examples of “based-on inhibition” training initiatives have been reported by Babai et al. (2012) to produce positive effects, but others, published more recently, could also be mentioned (Lubin et al., 2012; Rossi et al., 2012).

Finally, we believe that our results are interesting because they go beyond the binary and qualitative appreciation of conceptual/intuitive interference (or absence of interference) and promote a more quantitative appreciation of the effect that initial inclinations have on reaction times. We suggest that the next step could be to test more than five sub-conditions, or rather test analogue (continuous) values of intuitive interferences. We also believe that cognitive tasks like the ones that are referred to throughout this article should be used to test the value of pedagogical or didactical interventions for conceptual change. Indeed, not only do they give precise measurements instead of mere accuracies but they can also help teachers, educators and researchers to follow learning beyond the production of correct answers.

Acknowledgments

This research was made possible with the help of the Social Sciences and Humanities Research Council of Canada (SSHRC; grant number 365011) and by the Canada Foundation for Innovation (CFI; grant number 12751).

References

Aoki, T., Francis, P. R. & Kinoshita, H. (2003). Differences in the abilities of individual fingers during the performance of fast, repetitive tapping movements. *Experimental Brain Research, 152*(2), 270–280.

Babai, R. & Amsterdamer, A. (2008). The persistance of solid and liquid naive conceptions: A reaction time study. *Journal of Science Education and Technology, 17*, 553–559.

Babai, R., Eidelman, R. & Stavy, R. (2012). Preactivation of inhibitory control mechanisms hinders intuitive reasoning. *International Journal of Science and Mathematics Education, 10*, 763–775.

Babai, R., Sekal, R. & Stavy, R. (2010). Persistance of the intuitive conception of living things in adolescence. *Journal of Science Education and Technology, 19*, 20–26.

Borst, G., Poirel, N., Pineau, A. & Cassoti, M. (2012). Inhibitory control in number-conservation and class-inclusion tasks: A neo-Piagetian inter-task priming study. *Cognitive Development, 27*(3), 283–298.

Chi, M. (1992). Conceptual change in and across ontological categories: Examples for learning and discovery in science. In R. N. Giere (Ed.), *Cognitive models of science* (pp. 129–160). Minneapolis, MN: University of Minneapolis Press.

DiSessa, A. A. (2006). A history of conceptual change research. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 167–281). Cambridge, UK: Cambridge University Press.

Duit, R. & Treagust, D. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*(6), 671–688.

Duit, R., Treagust, D., (2012). Conceptual change: Still a powerful framework for improving science teaching and learning. In K. Shwee, D. Tan and M. Kim (Eds.), *Issues and challenges in science education research* (pp. 43–55). Berlin, Germany: Springer.

Dunbar, K., Fugelsang, J. & Stein, C. (2007). Do naive theories ever go away? Using brain and behavior to understand changes in concept. In M. C. Lovett & P. Shah (Eds.), *Thinking with data: 33rd Carnegie symposium on cognition* (pp. 193–206). Mahwah, NJ: Erlbaum.

Egner, T. & Hirsch, J. (2005). Where memory meets attention: Neural substrates of negative priming. *Journal of Cognitive Neuroscience, 17*(11), 1774–1784.

Evans, S. B. T. (2003). In two minds: Dual-process accounts of reasoning. *Trends in Cognitive Sciences, 7*(10), 454–459.

Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3*(4), 383–396.

Hewson, M. (2006). The acquisition of scientific knowledge: Analysis and representation of student conceptions concerning density. *Science Education, 70*(2), 159–170.

Houdé, O. (2000). Inhibition and cognitive development: Object, number, categorization and reasoning. *Cognitive Development, 15*, 63–73.

Houdé, O. & Guichart, E. (2001). Negative priming effect after inhibition of number/length interference in a Piaget-like task. *Developmental Science, 4*, 71–74.

Houdé, O., Pineau, A., Leroux, G., Poirel, N., Perchey, G., Lanoë, C., et al (2011). Functional magnetic resonance imaging study of Piaget's conservation-of-number task in preschool and school-age children: A neo-Piagetian approach. *Journal of Experimental Child Psychology, 110*, 332–334.

Houdé, O., Zago, L., Mellet, E., Moutier, S., Pineau, A., Mazoyer, B., et al (2000). Shifting from the perceptual brain to the logical brain: The neural impact of cognitive inhibition training. *Journal of Cognitive Neuroscience, 12*(5), 721–728.

Hsin, C.-T. & Wu, H.-K. (2011). Using scaffolding strategies to promote young children's scientific understandings of floating and sinking. *Journal of Science Education and Technology, 20*(5), 656–666.

Jensen, M. & Finley, F. (1995). Teaching evolution using historical arguments in a conceptual change strategy. *Science Education, 79*(2), 147–166.

Kelemen, D. & Rosset, E. (2009). The human function compunction: Teleological explanation in adults. *Cognition, 111*(1), 138–143.

Kelemen, D., Rottman, J. & Seston, R. (2012). Professional physical scientists display tenacious teleological tendencies: Purpose-based reasoning as a cognitive default. *Journal of Experimental Psychology 142*(4), 1074–1083.

Lafortune, S., Masson, S. & Potvin, P. (2012a). *Does inhibition have a key role to play in overcoming intuitive interferences in science?* Paper presented at the Neuroscience and education: 2012 meeting of the EARLI SIG 22.

Lafortune, S., Masson, S. & Potvin, P. (2012b). *Étude du développement cérébral de la capacité à surmonter des interférences intuitives en sciences*. Paper presented at the XVIIe Congrès de l'Association Mondiale des Sciences de l'Éducation (AMSE-AMCE-WAER)- Recherche en éducation et en formation: Enjeux et défis d'aujourd'hui.

Limon, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction, 11*, 357–380.

Lubin, A., Lanoë, C., Pineau, A. & Rossi, S. (2012). Apprendre à inhiber: Une pédagogie innovante au service des apprentissages scolaires fondamentaux (mathématiques et orthographe) chez des élèves de 6 à 11 ans. *Neuroeducation, 1*(1), 55–84.

Masson, S., Potvin, P., Riopel, M. & Brault-Foisy, L.-M. (2014). Differences in Brain Activation Between Novices and Experts in Science During a Task Involving a Common Misconception in Electricity. *Mind, Brain, and Education, 8*(1), 44–55.

Nersessian, N. J. (1998). Model-based reasoning in conceptual change. In L. Magnini, N. J. Nersessian & P. Thagard (Eds.), *Model-based reasoning in scientific discovery*. New York: Kluwer Academic.

Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20–40.

Piaget, J. & Cook, M. (1952). *The origins of intelligence in children*. New York: W.W. Norton and Co.

Potvin, P. (2011). *Manuel d'enseignement des sciences et de la technologie: Pour intéresser les élèves du secondaire*. Québec: Multimondes.

Potvin, P. (2013). Proposition for improving the classical models of conceptual change based on neuroeducational evidence: Conceptual prevalence. *Neuroeducation, 1*(2), 16–43.

Potvin, P., Turmel, É. & Masson, S. (2014). Linking neuroscientific research on decision making to the educational context of novice students assigned to a multiple-choice scientific task involving common misconceptions about electrical circuits. *Frontiers in Human Neuroscience, 8*(14).

Posner, G., Strike, K., Hewson, P. & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227.

Rossi, S., Lubin, A., Lanoë, C. & Pineau, A. (2012). Une pédagogie du contrôle cognitif pour l'amélioration de l'attention à la consigne chez l'enfant de 4–5 ans. *Neuroeducation, 1*(1), 29–54.

Rowell, J. A. & Dawson, C. J. (1977). Teaching about floating and sinking: An attempt to link cognitive psychology with classroom practice. *Science Education, 61*(2), 243–251.

Schroeder, et al (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the United States. *Journal of Research in Science Teaching, 44*(10), 1436–1460.

Shtulman, A. & Valcarel, J. (2012). Scientific knowledge suppresses but does not supplant earlier intuitions. *Cognition, 124*, 209–215.

Smith, C., Carey, S. & Wiser, M. (1985). On differentiation: A case study of the development of the concepts of size, weight, and density. *Cognition, 21*(3), 177–237.

Smith, C., Carey, S. & Wiser, M. (1992). Using conceptual models to facilitate conceptual change: The case of weight–density differentiation. *Cognition and Instruction, 9*(3), 221–283.

Smith, C., Carey, S. & Wiser, M. (1997). Teaching for understanding: A study of students' preinstruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction, 15*(3), 317–393.

Solomon, J. (1984). Prompts, cues and discrimination: The utilization of two separate knowledge systems. *European Journal of Science Education, 6*(1), 63–82.

Spada, H. (1994). Conceptual change or multiple representations? *Learning and Instruction, 4*, 113–116.

Stavy, R. & Tirosh, D. (2000). *How students (mis-)understand science and mathematics*. New York: Teachers College Press.

Thouin, M. (2001). *Notions de culture scientifique et technologique. Concepts de base, percées historiques et conceptions fréquentes*. Sainte-Foy, QC: Multimondes.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology, 37*(4), 571–590.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *The Quarterly Journal of Experimental Psychology, 54A*(2), 321–343.

Villani, A. (1992). Conceptual change in science and science education. *Science Education, 76*(2), 223–237.

Yeend, R., Loverude, M. E. & Gonzales, B. (2001). *Student understanding of density: A cross-age investigation.* Paper presented at the Physics Education Research Conference 2001.

Équipe de recherche en éducation scientifique et technologique, Département de didactique
Université du Québec à Montréal, UQAM
Succursale Centre-Ville, Montréal, QC, Canada H3C 3P8
E-mail: potvin.patrice@uqam.ca