Why Do Students Fail to Learn and Use Central Science Concepts or Simple Mathematical Notions?

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Abstract

Learning new highly formal scientific concepts such as force and energy or using mathematical concepts means, most of the time, understanding clear-cut relational concepts and/or perfectly defined algorithms. Once we understand them, no problem should arise using them. As we know, this is far from being the case. Students often fail to learn and apply scientific concepts in all the contexts, or for all the objects, they should be applied. Quite surprisingly, this is also the case for basic algorithms such as addition. We will illustrate these difficulties in these two conceptual domains. In the domain of physics, we will focus on the distinction of the notion of force and energy, describing a trajectory of developing, suggesting that what young children misunderstand can be predicted on the basis on the variables at play in a typical physical display. In fact, given the nature of the objects displayed in the problem (animate or inanimate), the location of the object, the status of the animate participant, students' answers regarding force and energy might change. These variables will be discussed obstacles to learning arising from world knowledge. In the field of mathematics, arithmetic problem solving is often described as the selection of the relevant algorithm in order to solve the problem. Here, we will suggest that the nature of objects and more broadly the world knowledge associated to these objects influences the way participants choose an algorithm, despite the fact that these properties of objects are mathematically irrelevant and should not influence solving procedures. Math experts and math teachers are usually unaware of these influences regarding mathematical performance, that, in fact, also influence math experts in the case of simple problems, which witnesses their pervasiveness. Overall, these examples suggest that even abstract knowledge might not be completely abstract and independent of the objects they are operating on. We will argue for the necessity to include them in the teaching strategy because they are cognitive obstacles to learning.

Keywords: *abstraction, physics, mathematical knowledge, obstacles to learning, world knowledge.*

Introduction

In highly formalized domains such as mathematics, or physics, or even morpho-syntax, a high level of competence means that people use a set of relevant dedicated formal devices. For example, in mathematics, if one understands what is at stake in an arithmetic word problem, he/she should be able to use the relevant algorithm in which the relations between quantities would be a perfect translation of the relations between the objects and entities that are referred to in the word problem. In scientific fields such as physics, understanding notions such as force and energy suppose that people are able to translate these concepts in terms of object properties and relations between objects in a way that is consistent with the scientific concepts. For morpho-syntax, the story is the same: competent speakers in a given language should be able to translate semantic relations between entities in the appropriate morpho-syntactic devices.

One important feature regarding these three domains is that the correct use of the relevant notions, formal devises, should not depend on the nature of the objects that are involved in a sentence, a math problem or a physical device. However, by contrast, our main claim is that mathematical solving procedures, or answers regarding physical concepts depend on the nature of the involved objects in a problem, that is, how we count depends on what we count. Before we come to math and physics, let's illustrate with morpho- case. It is now well-known that the way children between 3- to 8-years of age understand morpho-syntactic cues like the passive voice depends on the presence of semantic features that are syntactically irrelevant. For example, passive sentences with action verbs ("to hit") are easier than sentences with cognitive verbs ("to see") [1], [2], or semantically reversible sentences are more difficult than semantically irreversible ones. In the field of word arithmetic problem solving, it has been shown that both children and adults are biased towards specific solving strategy solutions depending on the nature of the objects targeted in the word problem.

Influences of irrelevant world knowledge in math

Studies have shown that non-mathematical semantic information related to the entities described in a problem influences lay solvers' performance [3], [4],[5].

Recent data show that isomorphic mathematical problems featuring weight quantities or duration quantities (see Table 1) did not elicit the same solving procedure. For both problems types, the same two solving procedures were available. The first one is "14-5=9; 5-2=3; 9+3=12). This solution relies on a composition of subsets. The second is "14-2=12", which starts with one total and subtracts the difference between the total and the non shared dictionary or duration (given that for the common dictionary or duration, the value does not need to be calculated since we know the difference between the characters for the other subset). Interestingly, despite the mathematical equivalence between the problems, participants massively use the first solving procedure for the weight problems, and used the second solving procedure for the duration problems. We interpreted this difference between the two procedures in terms of the nature of the quantities, cardinal in the first case, in the sense of a combination of subsets, and ordinal, in the second case, in the sense of a continuous axis. Most interestingly, when we introduced problems with a missing data which made the problem unsolvable using the first solving procedure but remained solvable with the second procedure, participants made more errors for the weight problems than for the duration problems. This is because, they spontaneously solved the weight problems with the first solving procedure. The duration problems led to no difficulty because they were not spontaneously solved with the first procedure. Most astonishingly, even math experts rejected the correct solution (using the second, ordinal, solving procedure) more often when it was proposed for the weight problems than for the duration problems. Again, mathematically, the fact that weight or durations were used was mathematically irrelevant.

Table 1: weight and duration arithmetic problems

Weight Problem	Duration
John takes a Russian dictionary weighing 5 kg He also takes a Spanish dictionary In total, he is carrying 14 kg of books Claudia takes John's Spanish dictionary and a German dictionary The German dictionary weighs 2 kg less than the Russian dictionary How many kilograms of books is Claudia carrying?	John took painting classes for 5 years He started taking painting classes at a specific age He stopped taking the classes at the age of 14 years Claudia started taking painting classes at the same age as John She took classes for 2 years less than him How old was Claudia when she stopped taking painting classes?

World knowledge in the physical domain: force and energy

Concepts like force and energy are highly formalized and should also be applied in all the conditions in which they are relevant. It is far from being the case as suggested by numerous studies [6], [7]. Megalakaki et Thibaut (2016) [8] studied the differentiation of the force and energy concepts for animates and inanimates, in children aged 10-17, in situations such as in Figure 1. Results showed that the younger students made no distinction between the two concepts for inanimate objects. They regarded force and energy as the objects' intrinsic properties, related to their height and weight, and tended to attribute both concepts to animates rather than to inanimates. With age, force continued to impinge on energy, the reverse being less frequent. Conceptions remained unchanged for the animate agents, insofar as younger and older students showed undifferentiated force/energy conceptions, relating both force and energy to the agents' effort or the results of their action. Overall, students tended to regard them as intrinsic properties, relying on the visible parameters and physical characteristics of the objects and agents. This interpretation is in line with a view of knowledge arising from sensory experiences. In fact, participants had difficulties ascribing force and energy to inanimates. Language use of the corresponding words also interferes with the proper treatment of these concepts.

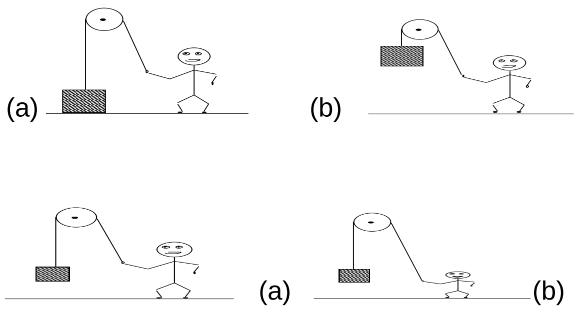

Figure 1: two situations involving characters interacting with objects. Participants had to describe them in terms of forces and energy.

Students' difficulties might also originate from the dynamic nature of these concepts and the necessity to simultaneously consider all the relations between the components of the system(s) into account. This difficulty can be ascribed to relational complexity. This notion accounts for difficulty solving problems or understanding sentences with the idea that the processing complexity of a task depends on the number of interacting variables that must be represented in parallel to perform the most complex process involved in the task. We believe that relational complexity provides an interesting explanation for the difficulty of acquiring the concepts of force and energy, insofar as the students initially regarded them as intrinsic properties, and their subsequent progress stemmed from the discovery of the relations between the different elements.

In sum, our world knowledge [9] dramatically interacts with formal knowledge and interferes both with its learning and its use in problems featuring objects and situations that are not congruent with the relevant technical notions.

References

(1) Thibaut, J., Rondal, J., & Kaens, A.M. (1995). Actionality and mental imagery in children's comprehension of declaratives. *Journal of Child Language, 22*(1), 189-209.

(2) Rondal, J. A., Thibaut, J. P., & Cession, A. (1990). Transitivity effects on children's sentence comprehension. *European Bulletin of Cognitive Psychology*, *10*(4), 385-400.

(3) Bassok, M., & Olseth, K. L. (1995). Judging a book by its cover: Interpretative effects of content on problem-solving transfer. *Memory & Cognition*, *23*(3), 354-367.

(4) Bassok, M., Chase, V. M., & Martin, S. A. (1998). Adding apples and oranges: Alignment of semantic and formal knowledge. *Cognitive Psychology*, *35*(2), 99-134.

(5) Gros, H., Sander, E., & Thibaut, J. P. (2019). When Masters of abstraction run into a concrete wall: Experts failing arithmetic word problems. *Psychonomic bulletin & review*, *26*(5), 1738-1746.

(6) Vosniadou, S., & Skopeliti, I. (2014). Conceptual change from the framework theory side of the fence. *Science & Education*, *23*(7), 1427-1445.

(7) Bayraktar, S. (2009). Misconceptions of Turkish pre-service teachers about force and motion. International, Journal of Science and Mathematics Education, 7, 273–291.

(8) Megalakaki, O., & Thibaut, J. P. (2016). Development and Differentiation of Force and Energy Concepts for Animate and Inanimate Objects in Children and Adolescents. *Research in Science Education*, *46*(4), 457-480.

(9) Thibaut, J. P. (1999). Développement conceptuel. In J.A. Rondal & E. Esperet (Eds.) *Manuel de psychologie de l'enfant*, Bruxelles, Mardaga, 343-384.