

The Danger of Misrepresentations in Science Education

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The science education literature has long recognized the importance student prior knowledge in shaping concepts, but is also keenly aware of the misconceptions that can emerge from it. However, factors that have been shown to lead to misconceptions include the overt or inadvertent misrepresentations of science content fostered by textbooks or through visualizations. In this paper we provide two vignettes of misrepresentations of physical principles to explain resonance and surface tension. We question the heuristic value of these representations, as they erroneously appeal to a student's prior experiences, are misleading on several levels, and have the potential of generating persistent misconceptions. Our aims are not to simply point out the misrepresentation and the misconceptions they lead to, but to explore the underlying roots and commonalities between them, and to offer solutions to clarify them.

Introduction

Misconceptions of scientific principles among students originate from a variety of sources including cultural background and everyday practice. However teachers and authors of textbooks are no less responsible for the erroneous views of their pupils [1]. Even the most concerned educators are often unaware of how misleading their presentation of the studied natural phenomena and processes may be for the students. Unfortunately, most learners have a single opportunity for formal instruction on the topic and thus retain a false, or at best a confused, understanding. Even worse, instead of supporting the earlier acquired knowledge, educational misrepresentations may violate the most basic scientific laws and thus undermine integrity of students' education.

We define a misrepresentation as an incomplete, misleading, or incorrect explanation, definition, construct, or metaphor of a complex phenomenon. We present an example of how an incomplete and misleading explanation with the concept of resonance and how an incorrect explanation using the concept of surface tension can lead to minor and gross misrepresentations of scientific principles.

Vignette I -Resonance

It is a very common practice to illustrate resonant phenomena with a 'pushing child on a swing' example which seems to be quite adequate and in a perfect agreement with the prior knowledge of the students. Textbook authors and teachers regularly claim that to achieve the

greatest increase of the swing's amplitude one should push it at the frequency that *exactly* equals the natural frequency of the swing's oscillations. The latter are reasonably assumed to be harmonic, as in Fig.1.

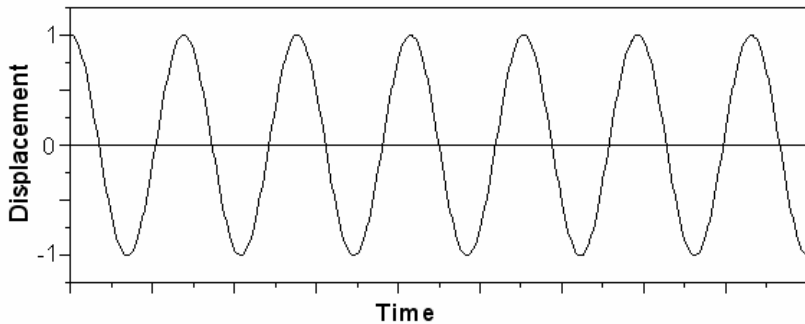


Figure 1: Free motion of the swing.

Pushing the swing once a period in an amplitude position is nothing like a continuous action, though. In particular, such a discrete impact produces a phase shift that changes temporal characteristics of oscillations – Fig.2.

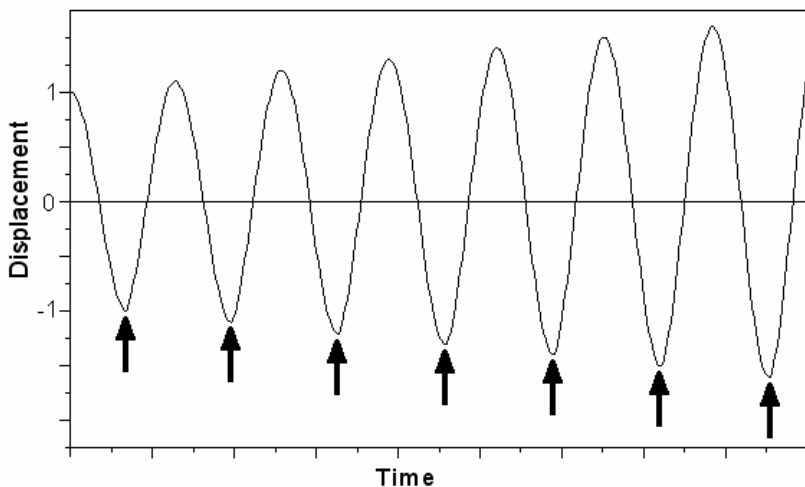


Figure 2: Pushing of a swing in an amplitude position once a period.

Addressing students experience in a more informal presentations, their instructors state that 'every kid already knows' that an *exact* coincidence of the frequency of external repetitive pushing with the swing's natural frequency is required to obtain resonance. Meanwhile, what every kid certainly knows is that pushing every period it is not necessary for a wide swing, one can miss it at random (the case of 'lazy pusher', Fig.3).

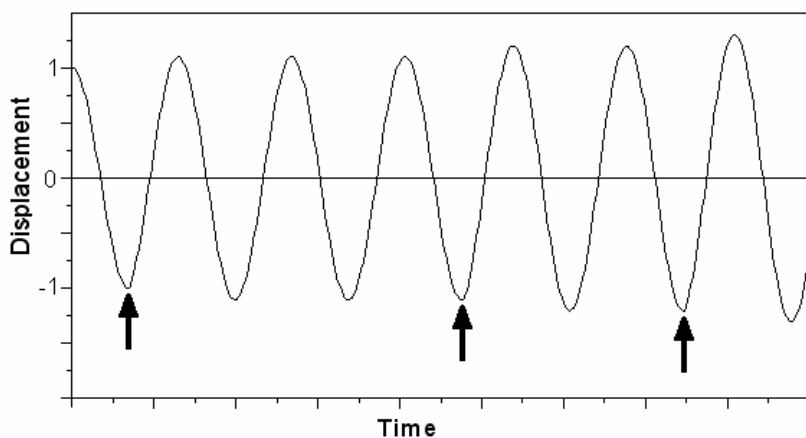


Figure 3: 'Lazy pushing' (some pushes are missed at random).

Moreover, kids well know that when they are lucky to have *two* laborious friends to push (Fig.4), the swing is reaching high amplitudes much quicker even though the strict textbook requirement seems to be violated: frequency of pushing is not equal but twice as big as the natural one.

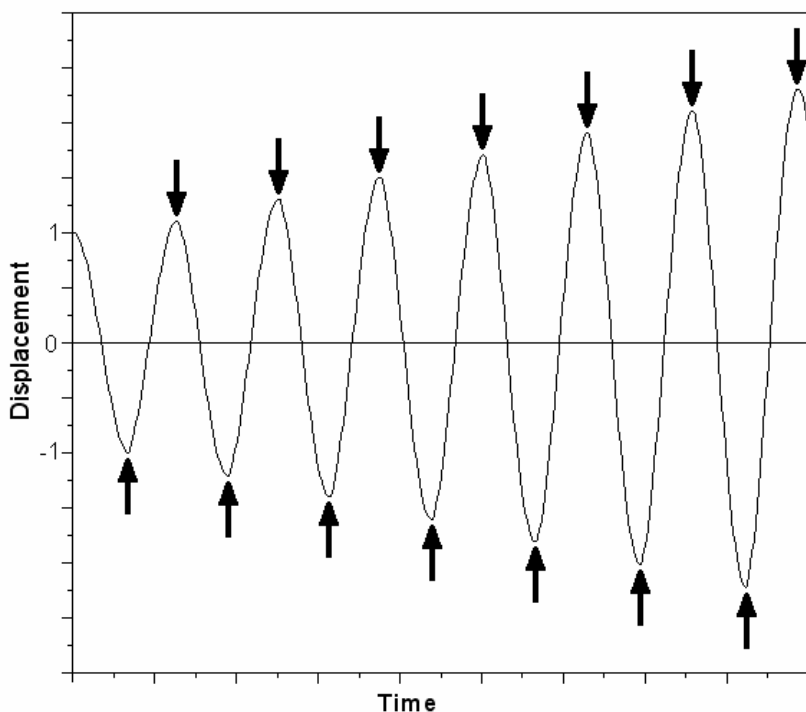


Figure 4: Pushing a swing at double natural frequency.

To go further with the kids' experiences: every child has a good idea how to damp and stop swinging. Even the ones too young to know the definition of the phase of oscillation know how to swing their legs at just the right moment to efficiently decelerate.

One is advised not to confuse the case of *harmonic* external force acting upon the system oscillating at single natural frequency with *pulse pushing* of an oscillating swing, which is a different problem. Otherwise, resonance that arises from discrete and continuous actions may be confounded. In a simple, 'conceptual' approach, 'pushing child on a swing' is a perfect model to discuss storage and release of energy, phase conditions, etc. [2]. An explicit spectral analysis of a series of acting pulses that requires from the students a solid mathematical background will justify their intuitive understanding of the swing's behavior acquired due to the vast swinging practice.

Also it is worth commenting on a 'classic' textbook example of resonant phenomena, the destruction of the Tacoma Narrows suspension bridge near Seattle, Washington (USA) by a strong wind. That is an essentially complex problem illustrated by the uniform air flow making flags flap [3]. A much more transparently resonant is an accident that happened in Angers, France, with a group of soldiers when persistent in marching in step on a bridge [2] caused its collapse. It is not hard to build a model for classroom experiments of the sort, to supplement the swing/pendulum demonstrations of mechanical resonances.

Vignette II - Surface tension

Surface tension is ordinarily explained by inward attraction of the outer layer of liquid from the bulk. According to this model, since the molecules in the surface layer have more neighbors inside the liquid than on the outside, this layer is attracted towards the interior, and an unbalanced net inward force is acting upon the surface molecules. But the Newton's Second Law of Motion leaves no alternative to the behavior of objects under the action of an unbalanced net force: they must accelerate. And thus this simple model requires eternal accelerated motion of surface molecules, which definitely is not the case. In other words, this common textbook model is erroneous.

A realistic model of molecular interaction [4,5] in the liquid accounts for both *attraction* and *repulsion* between the molecules depending on their separation (Fig.5a). For any pair of interacting molecules there is a distance r_0 of equilibrium between the attractive and repulsive mechanisms of inter-molecular interaction, zero force acting between the molecules and a minimum potential energy of the system U_0 , see Fig.5b.

The more neighbors around, the deeper is this minimum of potential energy, so less neighbored surface molecules are more energized than the bulk ones [6]. The entire outer layer bears an excess potential energy which is decreased as the area of the liquid's free surface is reduced. The sufficient mobility of the molecules in a liquid allows a random walk mechanism to account for a free volume of liquid reshaping into a sphere when gravity or other external forces are not dominant. But either inside the bulk of the liquid or on its surface, the *net force* of a molecule's interaction with the neighbors *is zero*.

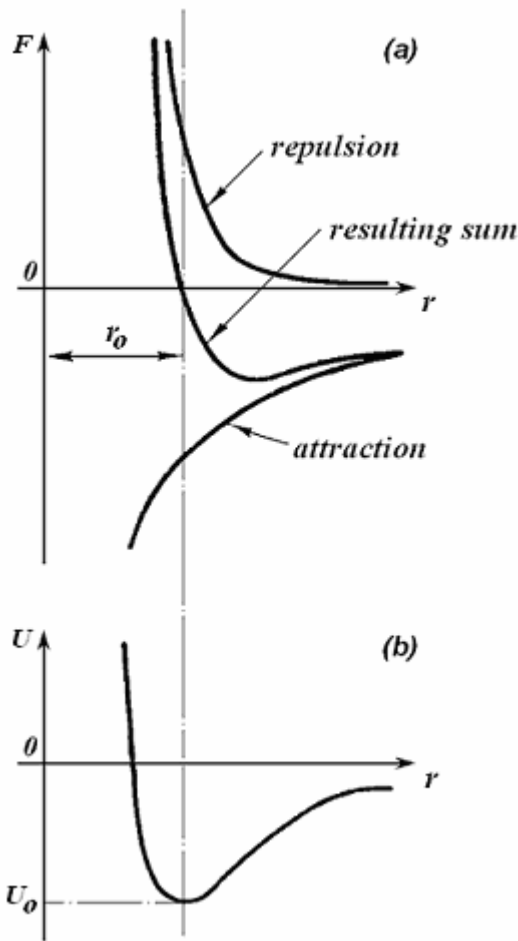


Figure 5: Forces (a) and energy (b) of inter-molecular interaction as a function of distance separating two molecules.

This gross textbook mistake is likely to originate from an over-generalization of the situation created in the liquid when the surface tension is measured by the standard method of stretching a film of liquid attached to a frame with moving side bar (Fig.6), or when children force air over or through a soap film over wire loop when blowing soap bubbles.

In both cases, under an action of the external applied force F_{ext} , molecules in the stretched film are pulled beyond their equilibrium distance r_0 (Fig.5a) into the range of attraction. Still there is no net force acting upon the molecules of liquid as the attractive inter-molecular force F_a is balanced by the external force F_{ext} .

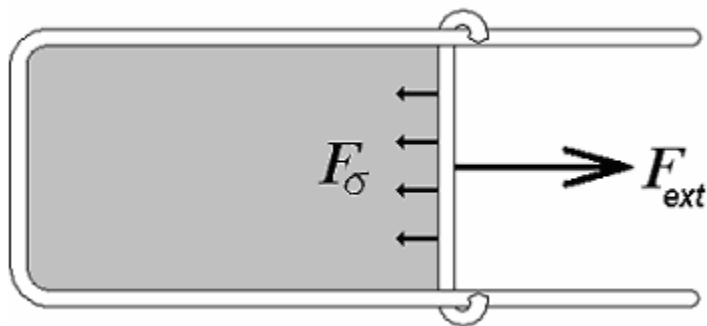


Figure 6: Apparatus for measuring surface tension by stretching the film of the liquid; forces acting upon the moving bar are shown.

Conclusions

Both examples cited above erred on the side of simplicity in order to convey complex interactions or phenomena, tapping into a student's prior experiences. Practicing teachers should beware the danger of a misleading explanation hidden on the textbook pages. Critical analysis of the traditional presentation of natural phenomena is mandatory and also provides a good opportunity for the teachers to apply and develop their creativity.

Acknowledgements

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