Critical didactic analysis – Misconception about the nature of surface contact forces

Introduction

The discussion of contact forces is a central element of each mechanics course. It appears, at a lower level, in the remedial activity courses, and in more debt in Physics NYA, a first-semester course for the Pure and Applied as well as the Health Science programs. It is this more detailed use in the NYA course that shall be discussed here. Physics NYA introduces the vector concept and applies it to kinematics, dynamics as well as conservation principles. The specific NYA course objective covering the surface contact forces is “to apply the concepts and laws of dynamics to the analysis of the translation of bodies”. The students are expected to know the common contact forces, recognize situations where they appear and use them appropriately when applying Newton’s Laws of motion to solve problems.

Most students already know the main contact forces, tension, normal-force and friction, and recognize the situations when they appear. However, a very common misconception is that the surface contact forces, friction and normal-force, have constant values. In their high-school courses, the students only encountered simple problems where the normal-force (F_N) was exactly equal the weight (m*g) of an object. This F_N=mg equivalency is further reinforced by the typical examples used to introduce the vector concept. Therefore, it is not surprising that the students fail to recognize that F_N=mg is a very special case, which is usually not true. This failure becomes critical when the simple examples are replaced by more complex problems and hunts some students throughout the entire course.

Similarly, many students believe that friction (f) has a constant value. Again, this is true in simple cases, mostly when involving kinetic friction. However, it applies to static friction only in exceptional cases. When introducing the static friction formula $f_s \leq \mu_s * F_N$, some students do not grasp the significance of the “smaller or equal”-sign and often even memorize the formula replacing the “smaller than or equal (≤)“ with “equal (=)”.

New instructional strategy: Analysis of surface contact forces using multi-dimensional scales

The suggested instructional strategy is a series of experiments using multi-dimensional scales. These scales are able to simultaneously record the vertical (the normal-force) as well as the horizontal component (friction) of the contact forces. They can be connected to a computer to produce histograms that show each force as a function of time. In order to be able to work with the undisturbed initial conceptions of the students, the activity should take place before discussing the contact forces in class or have the students read about it.

The activity is expected to take between two and three hours, depending how many scales are available (the students might have to take turns).

At the beginning of the experiment, each student is asked to write down his individual hypothesis of the relation between weight, normal-force and friction (the initial concept) and the results that are to be expected in five different situations. 1. Standing on the scale, placed on the flat surface without moving. 2. Standing on the scale while pushing on a nearby table. 3. Standing on the scale without moving, but placing the scale on an inclined plane. 4. Moving the setup into an accelerating elevator. 5. Jumping up and down on the scale. This initial part could also be done as a homework assignment prior to the experiment.

Once each student has written down his hypothesis, groups of two to four students take the measurements for all five situations. If time allows, the students are encouraged to try out any other setup they are interested in. After each scenario, the group is asked to write down if the observed forces can be explained using their original hypotheses. If their initial concepts do not work, they should try to come up with an alternative that explains the measured data. Finally, the students are invited to share their results with the whole class.

Hopefully, at least one team will come up with the conclusion that both, friction and normal-force are reaction forces that vary depending on the other forces acting on the object as well as the acceleration. They can therefore not be assumed to have a fixed values when used in Newton's Laws of motion. Instead, these forces are unknown variables. In case no team comes up with this conclusion, the teacher has to try to lead the student discussion in the desired direction. However, this has to be done without simply giving out the new idea. It is very important that the students themselves make the discovery.

Analysis

The activity aims to solve the issues caused by the initial student conceptions about the nature of surface contact forces. Unresolved, it is impossible to correctly apply Newton's Laws of motion in situations that include surface contacts – one main, if not the main learning outcome of the entire course. Students that assume fixed values will not be able to grasp the connection between these forces and Newton's Laws of motion. At best, these students will ignore their misconceptions and strictly apply the memorized procedures, leading to the very well known "surface problem-solving" – approach observed by many studies such as those of Chi, Feltovich and Glaser (Chi, Feltovich, & Glaser, 1981). In a worst case scenario, the interference of these unresolved misconceptions will lead to dead-ends when applying the standard problem-solving techniques, keeping the student from successfully analyze the situations.

The strategy builds on the findings by Buteler and Coleoni (Buteler & Coleoni, 2014). Instead of ignoring or replacing their initial concepts, the students are guided to refine them. Buteler and Coleoni's study shows that this leads to a much deeper understanding. The critical moment of the activity is the class discussion. If no team arrives with a working concept, the teacher has to intervene. Without teacher intervention, this could lead to a deterioration of the student performance (as documented by Lasry, Guillemette and Mazur (Lasry, Guillemette, & Mazur, 2014)), as the students have been shown that their concepts are not working, without having an alternative to work with.

Conclusion

I am confident that the outlined learning activity will help the students to resolve their problems with surface reaction forces. Considering the huge impact of this particular misconception on the overall course outcomes and performance, it is definitely worth spending a few hours for these experiments. The activity has not been tried out yet. Therefore measurable results regarding its effectiveness are missing at this point.

Bibliography

Buteler, L. M., & Coleoni, E. A. (2014). Exploring the Relation Between Intuitive Physics Knowledge and Equations During Problem Solving. *Electronic Journal of Science Education*, *18*(2). Retrieved from http://ejse.southwestern.edu/article/view/11993/0

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, *5*(2), 121–152. https://doi.org/10.1207/s15516709cog0502_2

Lasry, N., Guillemette, J., & Mazur, E. (2014). Two steps forward, one step back. *Nature Physics*, *10*(6), 402–403. https://doi.org/10.1038/nphys2988