Introducing mechanics by exploiting core causal knowledge

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Abstract

This paper concerns an 'in principle' outline of an introductory mechanics course. It is based on the argument that various uses of the concept of force (e.g. from Kepler, Newton and everyday life) share a common explanatory strategy, which has its basis in core causal knowledge. The explanatory strategy consists of (a) the idea that a force causes a deviation from how an object would move of its own accord (its *force-free* motion), and (b) an incentive to search, where the motion deviates from the assumed force-free motion, for recurring configurations with which such deviations can be correlated (*interaction theory*). Various assumptions can be made concerning the force-free motion, thus giving rise to a variety of specific explanations. Kepler's semi-implicit intuition is *rest*, Newton's explicit assumption is *uniform rectilinear motion*, while in everyday explanations a diversity of highly pragmatic suggestions can be recognized.

The idea is that the explanatory strategy, once made explicit by drawing on students' intuitive causal knowledge, can for students be made to function as a kind of advance organizer, as a general scheme that they know needs to be filled in but do not yet know how to fill in concretely for scientific purposes.

Introduction

This paper is about a new approach to introduce mechanics for academically streamed students of about 16 years of age. What we think is new about our approach, at least in emphasis, is our aim to provide students with *content-based outlooks* on what they are going to learn and why. We call our approach *problem posing*. The reason for this name is that one would have a clear case of students having a content-based outlook on what they are going to learn and why, if one could bring them into a position in which they themselves come to pose the main problems they subsequently would be going to work on (Klaassen, 1995, chapter 5; Lijnse & Klaassen, 2004).

We also aim to base our approach on a proper analysis of the relation between where students are (common sense) and where we want them to be (science). With respect to this relation we claim that explanations of motion, both from common sense and from science, can all be seen as fillings-in of the same basic structure, which has its basis in core causal knowledge. Differences between the various explanations are partly anchored in distinct explanatory interests.

Our idea is that the basic structure of explanation of motion, which we claim students command, at least implicitly, could for them be made to function as an *explicit directive guide* in learning about explanation of motion—as a kind of *advance organizer* (Ausubel, 1968). To the extent that we succeed in this, students can indeed be said to be provided with a content-based outlook on what they are going to learn and why.

The basic structure of explanation of motion

In this section we somewhat elaborate the claims,

- that explanations of motion, both from common sense and from science, can all be seen as fillings-in of the *same* basic structure,
- that this basic structure has its basis in *core* causal knowledge,
- that differences between various explanations of motion are partly anchored in distinct explanatory *interests*.

We refer to Klaassen (2005) for a more elaborate discussion of these points, partly in reaction to influential studies in the science education literature that claim the opposite.

Core causal knowledge

Our ordinary concept of causation is one of “things going on as they are unless interfered with” (Dummett, 1954). Figure 1, a slight adaptation of a cartoon by Gotlib (1970), is a simple illustration of the basic idea.

Fig. 1. Causes produce deviations from things going on as they are.

On the left we see a man taking a stroll. On the right we see the same man having the happiest thought of his life. The two situations are clearly different. Something must have caused the change. The picture in the middle shows what.

Of course, much more can be said about our ordinary concept of causality. In order to explain why not anybody who had an apple fallen on his head subsequently came up with the idea of universal gravitation, for instance, one may wish to distinguish between enabling conditions and trigger events. In order to meet the complaint that much more must have happened than the fall of the apple on Newton’s head, one may want to note that our notion of causality is shot through with interests. What is selected as ‘the’ cause of some event is some feature of the totality of causal factors that particularly interests the explainer. Usually it is something he finds surprising, or that he thinks his audience will find out of the ordinary.

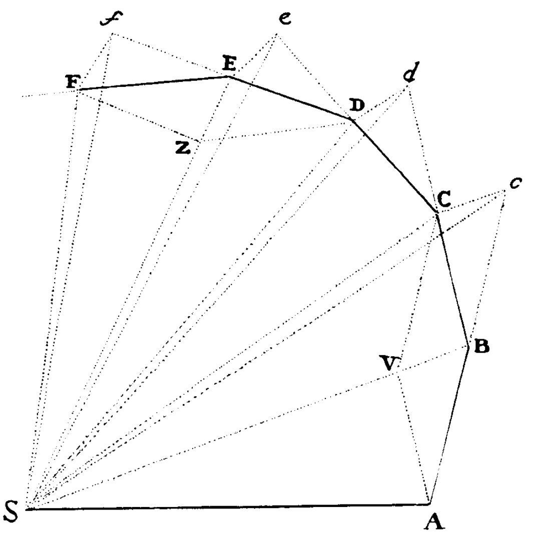
For our purposes, however, it suffices to just point out that causes effectuate *changes of state*. More formally, Descartes put it as follows: “each thing, provided that it is simple and undivided, always remains in the same state as far as is in its power, and never changes except by external causes” (1991, page 59).

Explanation of motion as a species of causal explanation

The picture of causes as effectuating changes of state can also be seen at work in explanation of motion. After all, explanation of motion is a special case of causal explanation. What gets explained are not changes of state in general, but changes of state of motion, and forces effectuate such changes.

A clear example of this can be seen in Newton’s construction method. The diagram on the left in figure 2 is taken from the proof of Theorem 1 of Section 2 of Book 1 of the *Principia* (Newton, 1999, page 444). Newton writes: “Let the time be divided into equal parts, and in the first part of the time let a body […] describe the straight line AB. In the second part of the time, if nothing hindered it, this body would (by law 1) go straight on to c, describing the line Bc equal to AB […] But when the body comes to B, let a centripetal force act with a single but great impulse and make the body deviate from the straight line Bc and proceed in the straight line BC” (1999, page 444). So the motion BC in the second time interval is compounded of a force-free motion (Bc) and a deviation caused by a force (BV). Newton’s assumption for the state of motion, or the force-free motion, is *uniform rectilinear*. Forces cause deviations from such states.

Fig. 2. According to Newton, of its own accord a body would move uniformly straight forward, and forces cause deviations from such states of motion.

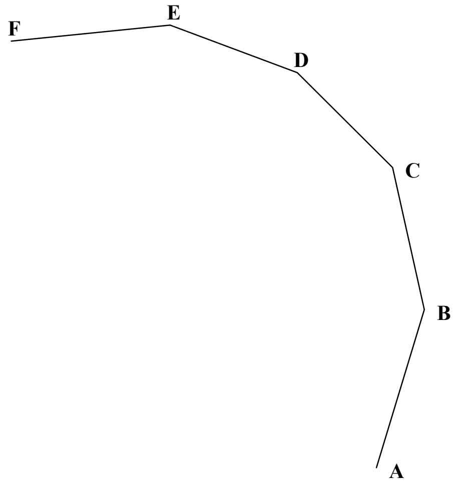


Newton

Other assumptions for the force-free motion are also possible. Kepler's assumption, for example, is *rest*, at least for celestial bodies. He writes: "a celestial globe […] has a natural αδυναμια or powerlessness of crossing from place to place, and it has a natural inertia or rest whereby it rests in every place where it is placed alone" (1995, page 54). Kepler's assumption cannot be refuted on logical grounds. But it does put on him the burden of finding appropriate forces to account for the deviations from his assumed force-free motion.

In order to account for planetary motion, Newton had to find forces wherever the planets deviated from uniform rectilinear motion, and to find the sources of those forces. Newton managed to do so by postulating a gravitational force of the sun on a planet. Kepler, on the other hand, had to find forces for any deviation from rest.

Fig. 3. According to Kepler, of its own accord a celestial body would remain at rest, and forces cause deviations from such states of motion.

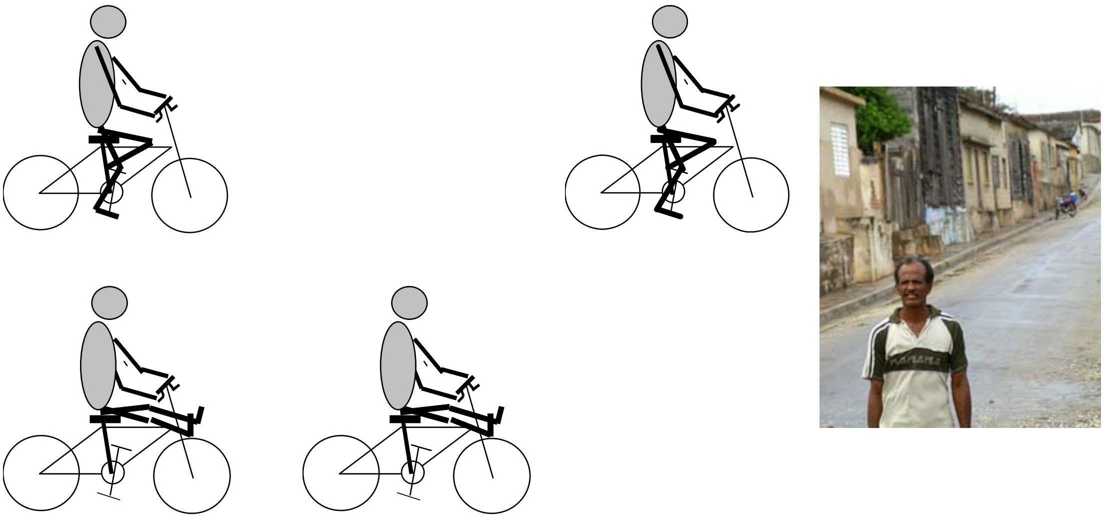


Kepler

In order to make a planet move like the diagram on the left in figure 3 (i.e. in the same way as in Newton's example from figure 2), a force is needed that pushes the planet from A to B, then from B to C, and so on. Of its own accord the planet would stay where it was. Kepler therefore had to find forces that were to drag, so to say, the planets along their paths, and to find the sources of those forces. Kepler managed to do so, as far as his mathematical capabilities allowed (Kepler, 1995; Stephenson, 1994). Of course we are not saying that Kepler's theory of planetary motion has the same scientific status as Newton's (it hasn't), but at least it shows that one can have a serious go at accounting for planetary motion under Kepler's assumption of rest as the force-free motion.

The very same explanatory strategy can be seen at work in the explanation of the man in the street why one has to keep pedaling to maintain speed (figure 4). The simple answer is: because if one stopped pedaling one would gradually come to a stop. In this everyday explanation, the force concerns a personal influence (pedaling) and the force-free motion is the motion of the object without this influence (slowly come to a stop).

Fig. 4. According to the man in the street, if the cyclist did nothing she would slowly come to a stop, but by continuing to pedal she prevents this from happening.



Similarities and differences between the various explanations of motion

There are clear differences between everyday explanations of motion on the one hand, and scientific ones on the other. Everyday explanation, for example, proceeds on a catch-as-catch-can basis and is pragmatically geared to actions we can perform. In particular, there is no need for a uniform assumption concerning the force-free motion. In other situations, e.g. hitting a target with a projectile, another assumption can be made, as long as it is checked by seeing plausible influences to account for the deviations from it.

Scientific explanation, on the other hand, has, amongst other things, a much more systematic character. In the end *every* deviation from the assumed force-free motion has to be accounted for by *exceptionless* force-laws. Due to these rather different explanatory interests, there is hardly any tension between everyday and scientific explanations of motion. Tension *does* arise between Kepler's scheme and Newton's scheme, and in the end Newton superseded Kepler. Just like, in turn, Einstein superseded Newton. Einsteinian mechanics (general relativity) contains yet another assumption for the force-free motion.

Let us now return to the similarities between the various explanations of motion. The similarities can be captured by a two-tier explanatory strategy that is common to all:

- a characterization of force-free states of motion, checked by
- a characterization of force-laws to account for deviations from those states.

This strategy can still be filled in concretely in various ways, thus giving rise to a variety of specific explanations, as the examples from Newton, Kepler and the man in the street illustrate.

What the strategy brings out is that "[t]heories of interaction and the notion of free—or inertial, or geodesic, or 'naturally moving'—particle are intimately connected" (Friedman, 1983, page 121). The strategy does not tell us, however, *what* we ought to choose as forces, states, laws, etc. It only sets *constraints* on such choices. It offers an explanatory *scheme* into which the choices we make must fit. As such, it functions as a *regulative principle* that directs and guides us in investigating the motions of bodies (Nagel, 1979, page 192).

An 'in principle' outline

The conclusion that the basic structure of explanation of motion functions as a regulative principle brings us back to our educational aims. Remember that our aim is to structure the learning process in such a way that students can *in advance* appreciate each step as *instrumental* to achieving the learning goals. What we now want to suggest is that the basic structure in explanations of motion, and the core causal knowledge in which it is grounded, can serve as an advance organizer, in the sense of dividing the vague initial question of how to explain motion into the instrumental questions of what might be appropriate fillings-in of the various elements of the basic structure.

The idea, therefore, is that students' process of gaining insight in explanation of motion can be supportively directed by a basic structure that students come to appreciate as in principle familiar (as underlying their own explanations), but also as in need of a different filling-in when explaining motion in an unusual (theoretical) frame of mind. In finding appropriate such fillings-in, help can be called in from pioneers on the field of explanation of motion: Kepler and Newton. Students' command of the basic structure will then help them to understand (simplified versions of) the theories proposed by Kepler and Newton *as* alternative fillings-in of the basic structure.

In short, students are expected to recognize various hypotheses as plausible alternative fillings-in of a basic structure that they know needs to be filled in. This is still very much an 'in principle' outline. It will be clear that a lot more needs to be done in order to make it work. It is not enough, for example, that *we* can see students' various explanations of motion as fillings-in of the same basic structure. Somehow they themselves should come to recognize:

- that explanation of motion, as a type of causal explanation, fits into a structure pre-formed by core causal knowledge;
- that fillings-in of this structure may be needed that differ from everyday ones, if one wants to understand why things move as they do in a frame of mind that is not governed by everyday concerns for practical control or satisfaction of mundane needs.

Only then can a motive to search for plausible alternative fillings-in of the basic structure come 'alive' in the sense of forming a real driving force behind the students' learning. Only then can their causal knowledge really function as a supportive and directive means to see a viable passage toward gaining insight in explanation of motion. Only then will students really see the point of what they are going to do. This, after all, is what our problem-posing approach is all about.

Concluding remarks

We designed an introductory mechanics course for academically streamed students of about 16 years of age (Klaassen, 2006). The first half of the course is based on the 'in principle' outline sketched above. The second half concerns the evaluation of the theories of Kepler and Newton for planetary motion. This part is based on the claim that the epistemic virtues usually associated with good scientific theorizing (empirical adequacy, generality, …) in the end are grounded in everyday plausibility judgments. So what can directively support students in the second half of the course, is their command of the appropriate epistemological resources needed to decide between alternative theories. In a modeling process of fitting and adjusting parameters, students are expected (1) to arrive at more or less adequate theories within both the Keplerian and the Newtonian scheme, (2) to weigh the relative merits of the two schemes in the light of the epistemic virtue of generality, and in the end (3) to make a validated choice for the Newtonian scheme.

A detailed evaluation shows that in earlier versions of our course we still fell short of reaching our aims (Westra, in press). The problems mainly concerned the first half of the course. One main problem was to make the basic structure 'come alive' in the sense indicated above, as familiar, somewhat elusive and yet providing a useful guideline. The other main problem concerned the problem of how to let it come 'alive' not just for individual students, but for a group of twenty to thirty students in a way that is manageable for a teacher.

Nevertheless, we still think that the 'in principle' outline can be made to work. We still believe that it is possible to tap students' causal knowledge and epistemic virtues in such a way that a sense of ownership is instilled in students concerning a viable way to tackle explanation of motion. We only need to improve our ways of tapping, so to say, and we think we are making progress in this respect (Emmett, Klaassen & Eijkelhof, 2006).

Let us close with a brief summary of our approach. We put a strong emphasis on *positively* exploiting students' existing knowledge, attitudes and abilities. In particular, we attempt to provide students with *content-based outlooks* on what they are going to learn and why. We try to do so by appropriately tapping some of their *core* knowledge, attitudes and abilities. We suggest that a similar approach be worthwhile for other scientific topics than mechanics too.

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