Chapter 3

Backgrounds of the design

1. Introduction

In chapter 2 some background concerning mechanics was discussed. Notions reported in the literature about the goals for mechanics, the problems in mechanics education, approaches to dealing with these goals and problems, and research methods were presented and discussed from which implicitly (and sometimes explicitly) my own view might have become noticeable. My view concerning these topics will be made more explicit in this chapter. I will start by discussing my goals for mechanics and problem analysis as part of this introduction.

My goals for mechanics are that (1) students come to know how mechanics works and (2) develop some appreciation for its power and range. The first goal is about how explanation of motion works. Understanding mechanics requires integrated understanding, in which concepts are connected to other concepts and familiar phenomena. In order to achieve such understanding an emulation of scientific practice and especially some need for a theoretical way of explaining motion which is part of a scientific practice seems useful. As was seen in chapter 2, sections 2.1 and 3.1 this is not an uncommon goal. The appreciation for the power and range of mechanics I aim for is primarily concerned with *understanding* why it is powerful and far ranging. Although such an appreciation will not readily motivate students to engage in studying mechanics, it can be motivating in an intellectual or theoretical way, not unlike the motivational aim in Advancing Physics discussed in chapter 2, section 3.1. With projects like Harvard Project Physics and Nuffield in mind some modesty seems in order in one's ambitions regarding the extent to which such goals can be reached.

To these two goals I add a third that is related to my problem analysis: providing students with a vocabulary with which the usual learning difficulties can be discussed. This third goal will be discussed in section 2.2 of this chapter.

Turning now to my problem analysis the reader may recall that I think that students' beliefs are basically correct, but that they differ in the meaning they attribute to words as 'force', 'inertia', 'mass' and 'acceleration'. This was expressed in terms of the explanatory scheme as that students have a different specifications of the explanatory scheme than the Newtonian specification (see chapter 2 section 3.2.1), which is understandable since they differ in their aims and interests for explaining motions. In my opinion the educational problem (or challenge) lies in making students change their aims and interests towards the 'theoretical orientation' required to appreciate the experts' aims and interests, which is a prerequisite for adopting the experts' choices for influence free motion and related influences and thereby the experts' meaning of terms like 'force'. What is basically correct in students' way of explaining motion, that is, what is already in agreement with the Newtonian way of explaining motion, is the underlying structure of explaining that I called the explanatory scheme.

The explanatory scheme forms the backbone of this work. It plays a role both in my problem analysis and my educational approach. In the problem analysis it serves a purpose in reinterpreting students' statements that are normally interpreted as alternative conceptions in a way that takes account of the interpretation problem. One could say that it solves the interpretation problem related to students' statements concerning mechanics. This was seen in chapter 2 section 3.2. In the educational approach it serves a purpose in providing a framework, in the sense that the topics of Newtonian mechanics can be introduced and can find their meaning as specifications of the explanatory scheme. Since it plays this central role I will argue for it extensively in the next section and present a first draft of how it may be applied in an introductory course for mechanics.

After that I will be finally able to formulate my research question in section 3, which also describes some specific aspects of the research method, developmental research, that I think are not widely known, leaving a full account of this method to other sources. For answering the research question it will be necessary to design education which is guided by my view on education and earlier (similar) design work, which will both be discussed in section 4.

2. The explanatory scheme

In this section I will argue for the idea of using the explanatory scheme in mechanics education. First, in section 2.1, I will further argue for the explanatory scheme as a backbone of causal explanation of motion. In section 2.2 I will argue for its relevance for education by exploring the question how the explanatory scheme for motion might become useful in contributing to reaching my goals of understanding mechanics, of appreciating its power and range and of providing students with a vocabulary with which the usual learning difficulties can be discussed. The condition sine qua non for appreciating this relevance is of course that the explanatory scheme for motion can be made explicit to students. I will turn in section 2.3 to the question how this condition may be met.

2.1. Causal explanation, in particular of motion

The explanatory scheme for motion was introduced in chapter 2, section 3.2.1, as a structure underlying all causal explanation of motion. In this section I will further elaborate this claim. I begin by bringing forward some simple facts about causal explanation. Subsequently I discuss the explanatory scheme for motion in this light. Because the scheme plays a pivotal role in my research, I close this section with a discussion of the status of this scheme.

What we want in a causal explanation of an event is information about the history of the event, from which it can be inferred that the event to be explained would follow. Two closely related steps are involved here: an appeal to causal laws or other causal lore, and a characterisation of the event to be explained and part of its history such that, thus characterised, the laws are applicable. Consider a simple example: why did this small red headed wooden stick catch fire? Well, that stick is a match and it was struck. What makes this into an explanation, is an (implicit) appeal to a very rough law like: if a dry match is struck sufficiently hard against a properly prepared surface, then, other conditions being favourable, it will light. The law becomes relevant because the object initially characterised as 'small red headed wooden stick' was redescribed as a match.

Obviously, this kind of explanation is not high science, if only because of the (implicit) use of failsafe clauses like ‘sufficiently hard’, ‘properly prepared’ and ‘other conditions being favourable’. Furthermore, if asked what a match is, most people probably cannot do much better than say that it is an object so designed that striking it causes it to light under appropriate circumstances.[1] Nevertheless, appeal to such rules of thumb is not empty either, if only because quite often it sufficiently supports our daily intercourse with events that must be foreseen or understood in the light of our everyday practical purposes.

The above discussion also introduces another main point concerning causal explanation: which laws are appealed to is interest relative, as are the concepts that are used in characterizing the event to be explained and part of its history. It depends on what we or our audience are interested in, on what we are able to deliver, on what we think our audience will be able to understand, and so on. ‘Because the vacuum pump did not function properly’ may well be (part of) the explanation of why a match did light, e.g. by someone who intended to convince his audience that the match would not light when struck in an environment with little oxygen. Furthermore, as already noted, in our daily traffic with events we perforce make use of sketchy summary generalisations involving causal concepts, precisely because they spare us the need to say what it is about, e.g., the match or striking it that explains why it acts as it does. We then simply assume that a vast number of (unspecified and unspecifiable) factors that might have interfered with the history leading up to the event to be explained did not interfere. We short-circuit part of what a fuller explanation would make manifest by appealing to more precise laws: laws that avoid or at least reduce the use of causal concepts, and clauses like ‘other conditions being favourable’ or ‘other things being equal’ (ceteris paribus). In the lighting match example, one may think of laws involving the concepts of friction and heat and laws involving the concepts of phosphorus, sulphur, oxygen (perhaps made explicit in exothermic chemical reaction schemes). It is clear that such concepts, in terms of which the relevant objects and events will have to be characterised in order for the laws to be applicable, only have remote connections with the descriptions under which the objects and events interest us for everyday purposes. Even more so if we were to appeal to laws governing the electromagnetic interactions between charged particles. But, of course, there are other interests than our mundane needs, among them those that are pursued in the various sciences. At the other end of a continuum of explanatory interests, for instance, we find the all-governing concern for maximum generality, for laws that are as precise, explicit, strict and as exceptionless as possible. In a developing physics we can hope to find generalisations whose positive instances give us reason to believe that they could be sharpened indefinitely by drawing upon the same vocabulary. This then points to the form and vocabulary of the finished system of laws, with a theoretical asymptote of perfect coherence with all the evidence and perfect predictability and total explanation under the terms of the system.

To summarize, in giving a causal explanation of an event we normally take for granted a great deal of background, and what we typically want to know is what to add to that

[1] In this sense the concept of a match is a causal concept, i.e. a concept that has the notion of causality irreducibly built into it.

background to make the occurrence of the effect intelligible. In order to achieve this it must prove possible to so characterise the event to be explained and the addition to the background that they fall under a (more or less strict and more or less lawlike) generalisation. What vocabulary and laws we settle on is to some degree a matter of the explanatory interests we happen to have. This I take to be rather uncontroversial facts about causal explanation. There are of course some controversial issues involved here, such as whether it is possible to analyse the notion of cause in terms of necessary and/or sufficient conditions, whether there is a non-question-begging criterion of the lawlike, or whether it is indeed possible, even in a developing physics, to free laws of all ceteris paribus clauses. I do not wish to take a stand on such issues, however, though I will later add an element to the above discussion that may be controversial. Now I first want to point out that the explanatory scheme for motion introduced in chapter 2 does indeed belong to the genus of causal explanation.

The explanatory scheme for motion, it will be remembered, consists in (1) a characterization of an influence free (force free) motion, checked by (2) a characterisation of plausible lawlike statements (force laws) in which deviations from this influence free motion are correlated with properties of the configurations in which those deviations occur. Where in general causal explanations one accounts for a deviation in some background *state* by identifying a cause, this state in the case of explaining motions is an object in influence free *motion*, deviations of which are accounted for by identifying influences. The explanatory scheme still allows for a variety of specific explanations of motion, with different assumptions for an influence free motion, which to some degree reflect the variety of explanatory interests we may happen to have. In everyday life, for instance, we take a strong interest in how to move objects from *A* to *B*, or to move ourselves from *A* to *B* by means of some object. Within this context, it makes good sense to consider as influence free motion the way in which the objects would move without our interference (stand still or gradually come to a stop), given that at the same time we happen to know enough rough laws in which relevant deviations from it (setting in motion, keeping in motion, braking) are satisfactorily correlated to kinds of actions we can perform. Given another goal, e.g. hitting a target with a projectile, another type of motion can be considered as influence free, as long as this is checked by the availability of sufficient rough laws to account for relevant deviations from *that* one. Many of the intuitive rules concerning motion are (related to) rough laws between kinds of actions and deviations from a particular kind of motion, as I have tried to illustrate in chapter 2.

Whereas commonsense explanation of motion is highly pragmatic, with conspicuous ties to action, explanation of motion can also be pursued in a frame of mind in which we want to understand things irrespective of whether we can control them and irrespective of whether such knowledge will advance our mundane goals. In the latter case, explanation of motion, though it may answer to various interests, in itself is not interest relative. *Every* deviation from the assumed influence free motion, whether it is of practical interest or not, has to be accounted for by means of appropriate, ultimately exceptionless force laws. Due to these rather disparate explanatory interests, there is hardly any tension between commonsense and scientific explanation of motion.

But also within one and the same theoretical mood, the explanatory scheme can still be detailed in a variety of ways, both logically and to some extent also historically realised. The explanatory scheme can be seen, for example, as structuring the Newtonian framework. It consists in (1) the specification of a kind of motion that is to count as influence free (uniform rectilinear motion), and (2) interaction theory to account for all deviations from this kind of motion in terms of force laws. Force laws, such as Newton's law of gravitation, are general statements that specify the forces objects exert on each other as a function of their total configuration (Jammer, 1957, chapter 12). Another, and less well known and developed way to detail the explanatory scheme is due to Kepler. It consists in (1) taking *rest* as the influence free motion, and (2) interaction theory to account for the deviations. This leads to a concept of force that differs from the Newtonian one. Keplerian net forces, just to name one difference, are of necessity always in the direction of motion. In order to account for planetary motion, Kepler imagined some kind of spokes emanating from the sun and pushing the planets along their orbits as the sun rotates about its axis (Barbour, 2001, section 6.6; Jammer, 1957, chapter 5). It is possible to make Kepler's idea precise and to formulate more or less plausible Keplerian force laws, which lead to the same predictions of planetary motion as within the Newtonian framework on the basis of a gravitational influence directed to the sun.

Within both the Keplerian and the Newtonian scheme, deviations from the assumed influence free motion provide motives to construct a theory that succeeds in accounting for the deviations. Because there are no guarantees that one will be able to do so, there does arise a rivalry between the two schemes. Their relative merits will have to be evaluated in the light of a shared commitment to the usual epistemic virtues associated with their fundamental aspirations, such as those of strict empirical adequacy and broad applicability. For further discussion of the status of laws of motion I refer to Nagel (1979, section 7.II) and Friedman (1983, section III.7).

I hope the above sufficiently places the explanatory scheme for motion within the realm of causal explanation. I will now close with a more fundamental discussion of the status of the scheme, or rather of causal explanation in general. It is based on the work of Davidson (e.g.: (Davidson, 1995; Davidson, 2001)).[2] I began this section by pointing at the (at least implicit) appeal to laws or lawlike generalisations in explaining why an event occurs. What will now be added to this is the suggestion that the conceptual connections between the notion of event (and other basic ones such as those of change, object, cause, substance and kind) on the one hand, and the notion of generality on the other, may be tighter than that they happen to both occur in causal explanations. What we have taken for granted in the discussion of explaining the occurrence of an event, for example, is what an event *is*, apart from an apparent incentive to provide an explanation. One natural proposal for a definition of an event or change might run as follows: some predicate P is true of an object at a given time t and subsequent to t P is no longer true of that object. This can only be right as a definition, however, if we have

[2] Similar ideas can be found in the work of others, amongst them Spinoza, Kant, and Hamilton, as is e.g. made clear by Heymans' (1890) overview of how the notion of causality functions in the work of philosophers from 17^{th} to the 19^{th} century.

independent means of saying what objects are or which predicates count as state-descriptions. But we do not have such independent means. In fact, the problem what a change or event is, is pretty much the same problem as what an object is or what states it can be in. Davidson's suggestion, as formulated by Ramberg (1999), is that '[w]hat we count as an object and what we count as a state of an object, as well as what we count as a change, is governed by our fundamental interest in construing our environment in terms of generalities. [...] to recognize a change in the state of a physical object just *is* to recognize an event which is susceptible to explanation in terms of empirical law. [...] our identification of objects and the changes they undergo implements and is given point by the explanatory generalizations to which they yield, and by which we manage our dealings with them. […] the observer of physical events cannot but see them as, on the whole, instances of how things generally tend to go. We couldn't fail to discover general relations by which we understand the changes we perceive in the physical world about us, because we are by nature disposed to count as changes and as persistent objects of such changes whatever will yield general patterns allowing us to predict our environment.' This fundamental interest in generality is very clearly encapsulated in the so-called cause-law thesis. It says that if two particular events are related as cause and effect (*a* caused *b*), that then there is a law (a lawlike generalization) to the effect that 'all events similar to *a* will be followed by events similar to *b*'. That is, we have reason to believe the singular causal statement only in so far as we have reason to believe there is such a law (and we may have good reason to believe there is such a law without knowing what the law is). Davidson's suggestion is that the cause-law thesis is built into the very application of the concepts of object, state, change, and so on. Similarly, it is constitutive of the concept of change that like changes will happen under like circumstances; and constitutive of the concept of object, that like objects undergo like changes under like circumstances.

The built in interest in construing our environment in terms of generality pulls together the whole continuum of non-mental sciences from our most primitive concepts of objects and their modifications to advanced physics. Not in the sense, of course, of providing a single all-purpose class containing all and only objects, a single all-purpose class containing all and only changes, and so on. The cause-law thesis and its variants only set *constraints* on what is to count as objects, changes, laws, and so on. They offer a *scheme* into which what we are to count as objects, changes, laws, and so on, must fit: 'events are changes that explain and require such explanations. This is not an empirical fact: nature doesn't care what we call a change, so we decide what counts as a change on the basis of what we want to explain, and what we think available as an explanation. In deciding what counts as a change we also decide what generalizations to count as lawlike. [...] if you can't explain it using one assumption of what counts as a change, adopt new categories that allow a redefinition of change. The history of physics is replete with examples of such adjustments in the choice of properties, thus altering what calls for a causal explanation.' (Davidson, 1995) Furthermore, the application conditions of the terms of the vocabularies of common sense and the various sciences are to varying degrees also constrained by whatever special interests are associated with them, and may thus trace different patterns of events. Still the characterisations they deliver are all, though each in its own way, geared 'to show up the general patterns in the changes that their objects undergo, general patterns the articulation of which amounts to providing a body of laws, or lawlike generalizations.' (Ramberg, 1999)

2.2. Relevance of the explanatory scheme for mechanics teaching

Let us explore the question how the explanatory scheme for motion might become useful for education. The explanatory scheme for motion will be useful for education when it somehow contributes to reaching the goals of understanding mechanics, of appreciating its power and range and, related to my problem analysis, of changing the aims and interest of the students and of providing them with a vocabulary with which the usual learning difficulties can be discussed.

A first basic idea that comes to mind when thinking about the explanatory scheme for motion's relevance is that it is the same in both common sense and Newtonian explanations of motion (as was seen in chapter 2 section 3.2.1 and in the previous section). In reaching an understanding of mechanics it might therefore provide a useful basis to build upon.

A first step in building on students' use of the explanatory scheme for motion would involve making this use explicit. If this first step is taken and students realise that the explanatory scheme for motion describes what they do when they explain motion, a second step can be attempted which involves recognising the explanatory scheme for motion in Newtonian explanations. In a third step the findings from the first two steps can be compared. Students can come to realise that Newton explained motions in a structurally similar way as they do. There are also striking differences in the choices made in specifying the scheme, like Newton's apparently peculiar meaning of 'force' and 'forcefree motion'. Comparing the explanatory scheme for motion in both their own and Newtonian explanation of motion will also point to their difference in terms of differing aims and interests and may therefore be useful in changing the practical aims and interests of the students in theoretical aims and interests of Newtonian mechanics.

However, such a direct comparison of students' and Newtonian explanations in the third step is problematic for two reasons. Firstly, practical explanations of students are already quite complex in Newtonian terms, because they usually involve multiple forces like friction et cetera. Secondly, in order to appreciate the more theoretical aims like strong empirical adequacy and broad applicability of Newtonian explanations some context is required in which a strictly practical explanation alone is unsatisfactory.

An alternative third step that involves mainly theoretical aims and therefore may take the previous objection into account is comparing explanations of Newton and Kepler of the motion of heavenly bodies. Since Kepler can be seen as a spokesman for common sense ideas about mechanics (notably rest as influence free motion and a 'force' always in the direction of motion), comparing Newton to Kepler is almost equivalent to comparing Newton and common sense. It is not essential that Kepler resembles common sense notions. As I will argue later any comparison as such will do, as long as both alternatives have theoretical aims. However, it can be expected that the stronger the students can recognise Kepler as a spokesman for their own opinions, the more committed they will be in the comparison. This alternative third step would also imply an addition to the second step, where the explanatory scheme is not only recognised in Newton but also in Kepler. I will first argue that comparing these two important historical figures might be useful and then that the context of motion of heavenly bodies is promising.

The choice for Kepler and Newton is based on two reasons. It will be remembered that firstly, both Newtonian and Keplerian models can be seen as specifications of the explanatory scheme for motion and can therefore be investigated from the perspective of the scheme and in turn illustrate the scheme. Secondly, both Kepler and Newton had similar aims and interests, namely to arrive at a general theory for the motion of heavenly bodies (and in the case of Newton even all motion). Comparing these alternative kinds of models requires criteria for evaluating (types of) models, that will not surface when comparing for instance a Newtonian explanation of some motion with a common sense explanation of the same motion. I will elaborate on these two reasons by sketching how comparing Kepler and Newton can help to reach the aim of understanding (Newtonian) mechanics and why the required criteria are important for my goal of developing some appreciation for the power and range of mechanics.

Both Keplerian and Newtonian models can be seen as specifications of the explanatory scheme for motion. An assumption for an influence free motion coupled with the identification of influences can be seen in both of them. They differ in the assumptions for the influence free motion (in this case rest and rectilinear motion with constant velocity respectively) and then of course also in the concrete influence laws and how this determines the motion precisely. The latter involves the concept of inertia and a 'second law'. So influence laws, inertia and a 'second law' according to both Kepler and Newton can be studied from the perspective of further specifying the explanatory scheme for motion. That means all of mechanics (with the possible exception of Newton's third law and Kepler's equivalent of Newton's third law[3]) can be introduced using the framework of the explanatory scheme for motion.

Comparison of alternative kinds of models, in this case Keplerian and Newtonian, can serve to find explicit criteria for evaluating these different kinds of models. These criteria provide the reasons for valuing Newtonian mechanics more than Keplerian mechanics. Since one of my main goals is to arrive at some sense of appreciation for (Newtonian) mechanics as an exemplary scientific theory, that is to say a theory that is far reaching or general, empirically adequate and plausible, these criteria are essential. Studying two alternative kinds of models quite naturally raises the question whether one kind of model might be preferable and how one could decide this. So the explanatory scheme for motion is relevant for reaching this educational aim.

I have explained why a comparison of Keplerian and Newtonian models seems useful, but not yet why this comparison might take place in the context of the motions of

[3] Newton's third law might be addressed as part of the interaction theory aspect of mechanics, where it serves as a constraint on force laws. Mechanics can be conceptually divided into an interaction theory consisting of force laws and the third law and a force-motion coupling theory consisting of the second law, kinematics and first law. Implementing a discussion of the third law into this approach seems quite possible, but was not attempted in this research. I will therefore refrain from further speculations regarding the third law.

heavenly bodies. The first reason for this is that explaining and predicting the motion of heavenly bodies is one of the big successes of science in general and mechanics in particular and therefore the historical example par excellence to illustrate its power and range, which was one of my aims. Secondly, these motions seem suitable to promote understanding of mechanics (another aim) since they are relatively simple for they involve only one influence (the complicating factor of friction is not an issue). Furthermore, motions in a curve also show in the Newtonian case more clearly deviations from the assumed influence free motion than do linear motions. One might object that investigating the motion of heavenly bodies introduces the complicating factor of a varying force, since gravity depends on distance and will therefore not be constant. This apparent complicating factor may not be that confusing when all calculations are left to a computer model. It may even prove useful to illustrate the fact that influences are functions of attributes of the configuration. (It’s not a bug, it’s a feature!) Thirdly, the context of motion of heavenly bodies quite naturally avoids triggering practical aims and interests and seems therefore suitable to instil a theoretical orientation, which was already argued to be important for both the goal of understanding mechanics and appreciating its power and range.

There is yet another reason why the explanatory scheme for motion is relevant for education: It may provide a vocabulary for addressing the usual learning difficulties in mechanics. In the language of the scheme the similarities and differences between common sense and Newtonian explanations of motion can be made explicit, and will strongly resemble the similarities and differences between Keplerian and Newtonian explanations of motion, I expect. Even common sense notions that do not resemble Keplerian notions can now more easily be addressed since criteria for valuing choices in specifications of the explanatory scheme have been established and comparing explanations has been practiced. Hereby students can come to understand why their explanation is unsatisfactory from a particular (scientific) perspective, but completely okay from another (practical) perspective. Also why one would prefer a Newtonian explanation over another, probably more intuitive, explanation given the aims and interests of science.

Take for example the following item from the FCI (item 5):

> A boy throws a steel ball straight up. Disregarding any effects of air resistance, the force(s) acting on the ball until it returns to the ground is (are):
>
> (A) its weight vertically downward along a steadily decreasing upward force.
>
> (B) a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.
>
> (C) a constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point, after which there is only the constant downward force of gravity.
>
> (D) a constant downward force of gravity only.

(E) non of the above, the ball falls back down to earth simply because that is its natural action.

A similar question about identifying influences is likely to occur in any regular course on mechanics. The given alternatives can each be discussed using the vocabulary of the explanatory scheme. For instance the plausibility of the upward force in (A), (B) and (C) can be questioned. Where does it come from? Finding some kind of plausible regularity relating this influence to attributes of the configuration, e.g. the hand, may prove to be very difficult. Also the question can be raised what influence free motion seems to be assumed in the various alternatives. Alternative (E) shows falling down as assumption of an influence free motion that differs from Newton's assumption. This explanation is therefore not Newtonian (Aristotelian in fact), but does account for the downward motion. It does not mention or explain the upward part of the motion. Reasons for preferring a Newtonian explanation to another common sense or Aristotelian explanation can at such a point be recalled (its empirical adequacy, plausibility, range, et cetera). Another question that can be asked is: Why does the identified influence has to be there? Answering this second question is for many students reason to identify an upward influence for the first upward part of the motion. Here can be recalled that in the case of Newtonian explanations it is not necessarily the case that there is always an influence in the direction of the motion. A Newtonian explanation using a single constant downward influence can account for this motion, which can be shown with a computer model or graphical construction.

Until now I have argued in this section for the relevance of the explanatory scheme for motion in teaching mechanics. The condition sine qua non for this relevance was that use of the explanatory scheme for motion by students could be made explicit to students (step 1). Then use of the explanatory scheme for motion by Newton could be made explicit (step 2). I also argued that comparison of Newton's use to Kepler's use is preferable to a direct comparison to the students' common sense use. In the next section I will turn to the question how the first condition of triggering and explicating the explanatory scheme may be met.

2.3. Triggering and explicating the explanatory scheme

It is important to note that the idea that causal explanations of motion can be interpreted from the perspective of the explanatory scheme for motion itself is not a hypothesis to be tested. I take it to be given for this research. Of course, it is not given as a matter of fact and I have given arguments for it in section 2.1. But, as argued there, the status of the explanatory scheme is so basic and constitutive for how one understands the world that it is among the last things I would give up. The question I am interested in here is not whether students make use of the scheme, but *if* and *how* this use could be made explicit to students as a first step in making the explanatory scheme productive in teaching/learning mechanics. Although students make implicit use of the explanatory scheme for motion they most likely are unaware of this. This can be compared to people almost all the time making correct implicit use of logical rules in their conversations, but without formal training in logic they will be unable to explicate any of these rules.

Since I expect to be able to recognise the explanatory scheme for motion in all explanations of motion, a first idea to implement this idea in a course on mechanics could be to get students to explain motions, so that their use of the scheme could be pointed out to them in these explanations they themselves have given. But how can such explanations be triggered? With 'triggering the explanatory scheme' I simply mean making students explain motions. They do not have to realise themselves that what they are doing is 'explaining' a motion, as long as *I* can recognise an explanation in what they say. Furthermore, when students come up with explanations of motion, can the explanatory scheme for motion be explicated? And how? With 'explicating the explanatory scheme' I mean pointing out the scheme in their explanations in a way that students can understand. This understanding can vary from merely being able to follow what is said when the scheme is explicated, to being able to fill in elements of the scheme when asked (e.g. a correct response to 'what influence did you identify?'), to pointing out the scheme themselves without prompting questions (e.g. a correct response to 'how is the scheme used in this explanation?'). This last level I do not expect to be easily reachable. The extent to what they will be able to use the scheme themselves is uncertain.

Without a proper introduction of the explanatory scheme it will not be able to function as a guide for the rest of the introductory course and I would have fallen at the first fence. Since the start of the course has this importance and it was uncertain how the scheme could be properly explicated I decided to explore a particular idea of involving students in explaining motion in a pilot study, which I will describe shortly.

In this pilot study I tried to trigger the explanatory scheme for motion by showing (after one trial run) three pairs of 15 year old high ability students[4], which resembled the target group for the introductory course (see chapter 2, section 1)[5], video fragments of different motions:

1. a bicycle rider riding with constant speed
2. a bicycle rider not pedalling and coming to a stop
3. a tired ice-skater who continues to glide after a race
4. a basketball player taking a penalty shot
5. a race car taking a turn
6. a ball in a circle with gap.

Each fragment was paused after a couple of seconds and then the students were asked 'How will this motion continue?' and 'Why will this motion continue in this way?' The latter question is expected to trigger an explanation of motion. After having answered

[4] These students had already received some education in mechanics in the lower grades, but this can be considered irrelevant for our purposes.

[5] Although the target group consists of fourth grade (16 year) pre-university students before the regular mechanics course, these third grade (15 year) students were considered similar enough. In fact, since this pilot occurred shortly before the summer vacation, these students were only 3 months away from matching the target group perfectly.

these two questions the fragment continued and the students could see if their prediction was right. From these conversations about motions I then tried to explicate the explanatory scheme. Why in this way?

The first three fragments were meant to trigger the mentioning of two types of influences: personal influences, something a person does or does not do to change a motion (like pedalling and braking) and non-personal influences, something the environment does which changes the motion (like slipperiness and resistance). The division of influences in these two types was meant to make the concept of an influence free motion easier by first considering only personal influences to be absent, which was expected to be easier because students have a plausible interaction theory available to explain deviations from the influence free motion. Students have experience with or can easily imagine what will happen with or without some personal influence, whereas they do not with non-personal influences. The plan was that after considering only the personal influences then the more difficult step can be taken of considering all influences to be absent. I would then explicate the scheme by pointing out that there is a certain way in which they, the students, explain these motions. They have all identified influences on the motion, I expect mentioning of e.g. pedalling, braking and 'being slippery' or 'resistance' or whatever the students put forward. In their explanations of some motions the identification of influences must, at least implicitly, have been accompanied by an assumption of what would happen with the motion when these influences were absent. I would then try to give an example from the answers of one or two students. I did not expect students to grasp completely the idea of the explanatory scheme for motion at this stage. I did expect them to find the categorisation into personal and non-personal influences straightforward. Three more fragments were shown and discussed to identify some more influences, to practice with the explanatory scheme for motion and to notice what one might assume for influence free motion.

Data gathering, analysis and presentation

I have chosen interviews with pairs because then the students can interact with each other and the interview may be perceived as less frightening than when students are alone. When there are more than two students in a group managing problems may make it more difficult to flexibly react to what happens. Since this pilot study only aimed to get some grip on and feeling for the triggering and explicating of the explanatory scheme few interviews were thought to suffice. The interviews were audio taped and transcribed. The analysis of the interviews consisted of a comparison of the actual conversation with the expected one, which was described in an extensive interview plan. Expectations were made explicit for this reason (enabling the analysis) and also to facilitate the actual interview. My interpretation of all three interviews was discussed with a second researcher, who read the interview protocols. Most of the time agreement about a particular interpretation was reached. Only those instances of agreement were used to base conclusions on.

In the presented fragments the teacher will be indicated with 'T', the students with the first letter of their first name, except when this could be confusing in which case the first three or four letters of their first name will be used and the researcher or interviewer with 'I', throughout this thesis. Pauses are indicated in parentheses by their length in seconds, e.g. '(3s)' means a pause of three seconds. Dialogue written in parentheses means that I could not hear that part very well. Statements written in square parentheses are comments from me. The fragments were stylised in two ways. Firstly literal repetitions and humming were deleted. Secondly spoken language was transformed in 'written spoken language' by deleting stutters, too many ahs and ehms, not functional repetitions and adjusting the grammar.

Results

The first three video fragments sufficed in triggering examples of personal and non-personal influences. Comparing fragments showed the need for another influence like friction or resistance. There are clear examples of students' use of the explanatory scheme in all interviews, so this way of triggering the scheme worked as expected. The following is a representative example of this use of the explanatory scheme in which a bicycle rider not pedalling and a tired ice-skater who continues to glide after a race are compared:

1. I: When you compare this [fragment] now with that bicycle rider gradually coming to a stop, are there any differences?
2. B: Yes, she is standing on her own legs. The girl on the bicycle is again something else. She can control herself with her legs, so she does not start to wobble.
3. E: The one on the bike also falls when she stops, because she is standing on one thing. That skater will not fall, for she has two irons.
4. I: Other differences?
5. E: The girl on the bicycle also has to pull on and turn her steering wheel to keep on end.
6. I: Imagine that the ice skater never brakes nor will be forced to go to the side because of a next race, what will happen then? Will she continue riding rounds?
7. B: No, she will go slower and at a time come to a stop.
8. I: But how does this come about?
9. E: Because she has no more speed. She does not make any new speed and the speed she had at the beginning will be exhausted.
10. I: Can you also say such a thing with the bicycle rider: She has a certain speed and that will be exhausted?
11. B/E: Yes.
12. I: But how does it come about that the bicycle rider comes to a stop much more quickly?
13. E: More resistance of the tires and the surface of the road.
14. B: Yes, ice is more slippery.

There is an unexpected focus on another than the expected non-personal influence, namely balancing. The ice skater can balance by using both legs (2, 3). The bicycle rider balances by pulling and turning her steering wheel (5). In this an unexpected use of the explanatory scheme for motion can be found: The identified influence (balancing) causes a deviation, in a way which is known to be effective, from what would have happened without that influence, namely falling. After the interviewer tried to shift the focus of attention to the decelerating (6), another (and more expected) form of the explanatory scheme for motion was found (7, 9). She will go slower and at one time stop, because she does not *make any new speed* (=influence) and the speed she had will have been exhausted. The influence free motion in this case is a 'depleting speed' or deceleration. The third fragment as such did not trigger new influences, as expected. By comparing the fragments students could readily name a non-personal influence, resistance (13, 14), which was the purpose of the comparison. In order to be able to give such an answer it is essential to have a plausible regularity available relating resistance to more quickly coming to a stop, like 'more resistance results in more quickly coming to a stop' or 'slipperiness results in less quickly coming to a stop'.

The students agreed on what would happen with a motion when all personal influences are left out of consideration. This setting aside of personal influences was in the three video fragments not perceived as a strange thing to do. The next step, setting aside *all* influences was after that still difficult but at least not a strange thing to do. The students were willing and able to think along in these terms of the explanatory scheme, that were therefore to some extent clearly explicated for them. As expected, the result of what would happen with the motion in that case was not so clear and students simply did not know or had no clear ideas about this influence free motion and therefore neither about an interaction theory. This however concerned the specification of the scheme. The main point here is that they were able to consider what these concrete specifications might be. Take to illustrate this point the following explanations of two students about what would happen with the motion of a thrown basketball after setting aside all influences.

Question: What would happen with the motion when we set aside all influences?

1. E: It will remain floating. At some time.
2. I: Do you also think that?
3. R: Yes, it will just continue according to me.
4. I: How should I see that?
5. R: It will keep the direction in which it is thrown, I think.
6. I: E, you said that it would remain floating.
7. E: Yes, at some time it stands still.
8. I: Immediately? Or how should I see that?
9. E: Immediately. I think it stands still immediately. The [basketball] player did not provide it with any force.

The students could fairly easily be let to consider what would happen when these influences were absent. They did not show signs of misunderstanding the point or meaning of the question, but instead offered different speculations for a choice for influence free motion. E assumed rest (7, 9) and R assumed rectilinear motion (3, 5).

One exceptional student, Roland, could even apply the practiced way of explaining motions to the example of a race car taking a turn, which was used in one of the try-outs of these interviews:

1. I: How will it continue?
2. [E: It will take the turn.]
3. R: It will just continue.
4. I: Ok. I have asked you several times before. Now try to explain this all by yourself, like we did with the other examples. You start (Roland).

5. R: Eh, according to me, with resistance it will normally continue, but then you have to keep applying force. When there is no force left, it will eventually come to a rest. When there would be no resistance, it would continue indefinitely.
6. I: Ok, but who is applying force?
7. R: Ehm, yes, the engine is, rather.

The motion that is explained is not the turning of the car, which was intended with this fragment, but the continuation of the car (3). Roland identifies two influences: a 'force', he later attributes to the engine (7), and resistance. He sets aside first the 'force', leading, resistance still being there, to the car eventually coming to a rest. Secondly he sets aside resistance too, leading to the car continuing indefinitely (5). That he is able to correctly apply the scheme indicates that he must recognise its logic.

In conclusion can be said that the triggering of the scheme went according to plan and it was rather easy. The extent to which the scheme could be explicated in the course of one interview can be described in the following way. Students were not particularly surprised or confused with my account of the explanatory scheme and they could be led to consider questions like 'which influences are working' and 'what would happen when all influences would be absent' in a quite natural way. This indicates that they had some understanding of the meaning of the scheme.

3. Research question and method

In section 2.1 I discussed the explanatory scheme and its status. I have indicated the didactical possibilities of this scheme in section 2.2 and presented some indications that it can be triggered in and explicated to students in section 2.3 to continue on this path. The remaining question I would like to explore is whether and how this can be made productive, concrete, in real life education.

My research question is how the idea of a common explanatory scheme for motion in common sense and Newtonian mechanics can be made productive in teaching/learning mechanics.

Although the idea of the explanatory scheme for motion might be applied to a complete mechanics course for secondary education, such an endeavour would be unnecessary for exploring how this idea may be made productive. I therefore decided to apply the idea in a design of an *introductory* course. Normally in an introduction of any study topic one expects to find what the topic is about and some indication of the importance of studying the topic. In my case this fits in nicely with my aims of giving students some sense of how mechanics works and the power and range of mechanics. This introduction does not replace the normal course in mechanics students receive, but is simply something extra at the beginning. To distinguish between the introductory course I designed as a means for answering my research question and the regular course that follows this introduction I shall henceforth call the former 'introductory course' and the latter 'regular course'.

In the regular course productive use of the introductory course could be made by placing the details of the regular course in the bigger picture provided for by the introductory course and by using the vocabulary of explanation to address alternative explanations of motions that inevitably will occur. This will require some slight additions or adaptations in how the regular course is executed. Indications for the teacher as to how the introductory course could be used in the regular course will be part of my design. Whether this use will turn out to be productive is part of the research question. The research question concerns therefore both how the scheme can be used in a design of an introductory course that will lead to my educational aim of making students appreciate the power and range of mechanics and know how mechanics works and whether this course will provide the vocabulary to address the usual learning difficulties reported in literature to be used in the regular course following this introductory course. There is of course the possibility that the scheme cannot be made productive at all. For this to conclude many attempts of putting it to work would have to have been made, and this can therefore not be an outcome of my research[6]. I *can* come to the conclusion that *my* attempt of making the scheme productive failed, of course.

Design research

I will attempt to answer the research question by means of a design experiment. I will not say much about the general features of and rationale behind design experiments (also called design-based research or developmental research). That has been done extensively elsewhere (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003); (Design-Based_Research_Collective, 2002); (Lijnse, 1995); (Lijnse, 2003). Suffice it here to say that trying to make the explanatory scheme productive in teaching/learning mechanics is quite a novel idea of which it is unclear how it can be done. By designing and testing some prototype of designed education and then revising the prototype and testing it again and so on in a cyclic process one can come to grips with this question of how it can be done. Such a design can be expected to suffer from many growing pains. Enough of these will surface in one trial with one class taught by one teacher. One such trial will result in a plethora of indications for revisions in the design[7], which, after being revised, can be put to the test again. Such a second trial can be expected to still suffer from growing pains, albeit hopefully less so than in the first trial or at least differently.

Testing a design raises some important methodological points that need to be taken into account when applying this research method. Firstly, the didactical quality of the design has to be object of study. When a domain specific didactical theory is the aim, all the aspects of the teaching/learning process, like the teacher's role, the learning activities or just 'what happened in the classroom', and their interrelatedness should be studied. "Didactics concerns the organisation of the content to be learned both in a sequence of successive learning activities and in supportive teaching activities, in such a way that it supports the learning process of the students and the learning goals are sufficiently met" (Westbroek, 2005, p. 51). Secondly, expectations need to be formulated, thereby making it clear to understand why the design was designed in the way it was. Behind a

[6] How many trials are needed before one concludes that something cannot be done? If one is stubborn enough one can always say: 'try harder'. Perhaps the deciding factor is the availability of a better alternative.

[7] Anyone with some experience in any kind of design knows that the first prototypes will not work as intended. Earlier experiences in designing education, e.g. (Knippels, Waarlo, & Boersma, 2001; Kortland, 2001; Verhoeff, 2003; Vollebregt, 1998) indicate the same finding.

design ought to lie some justification of why this design is expected to do what it must do. These expectations are then subject to empirical testing, resulting in further improvement of the design and to a domain specific didactical theory as result.

An important tool for ensuring or helping that the just mentioned methodological issues are addressed is the *scenario*. It describes and justifies in considerable detail the learning tasks and their interrelations as well as the actions that students and teacher are expected to perform. It can be seen as a hypothesis, as a prediction and a justification of the teaching/learning process that is expected to take place. As such, it also enables the researcher to precisely observe where the actual teaching/learning trajectory deviates from what she expected, and thus to test her hypotheses in a valid and controllable way.

In the scenario a justification is given for each teaching/learning activity, of why this particular activity should take place, what the local goals of the activity are and why this activity would be expected to meet these goals. All successive local goals should of course lead to the global goal of giving students some sense of how mechanics works and some appreciation of its power and range. Such an explicit description allows for the didactical quality of the design to be object of study. More details on the scenario will follow when I present my scenario for the introductory course in chapter 5.

There are some practical considerations that influence this research. Time restrictions allowed two consecutive trials. The lesson time available for trials was ten 50 minute lessons for the first trial and twelve 65 minute lessons for the second trial. The choice for the length of the course is based on the following considerations: The length is restricted by the number of lessons a teacher is willing to spent on such a course instead of the regular program and by the amount of data the researcher is capable of handling in the course of a 4 year research project. Of course also a minimum amount of lessons is needed to develop the basic idea.

The choice for the target group, upper level pre-university students (age 16), is based on my expectation that the required ‘theoretical mood’ (see section 1 in this chapter) can more easily be developed in academically inclined pre-university students. Also at this stage students start with mechanics in the Dutch educational system[8], making an introductory course appropriate.

4. Theoretical guidelines for the design

In chapter 2 approaches contributing to solve the problem of lack of understanding in mechanics were divided in three categories: theories about the problem (that might be used by others in application to education), guidelines for teaching, and spelled out education (in the form of learning materials, teacher guides et cetera). It may be clear from the previous section that I opt for the third category. Only in a developmental

[8] In earlier grades students studied mechanics as well, but this background I consider to be irrelevant for my purposes. The fact that mechanics in upper level secondary school effectively starts all over again points to a similar lack of confidence in students’ knowledge and skills concerning mechanics acquired in lower level secondary education by teachers and schoolbook writers.

process of designing and redesigning concrete real-life education can the question how the idea of an explanatory scheme for motion be used productively in teaching and learning mechanics be answered. The devil is in the details. In my opinion the task of applying educational guidelines based on research of some particular kind is difficult and time consuming and is therefore not solely the job of teachers. In order to improve education in mechanics one should come up with something more explicit than guidelines for teaching, that is to say, concrete developed education.

Developing some course will show to some extent the views on teaching and learning of the developer. These views can be seen as guiding the design and are important to be made explicit, which will be done in the next section, section 4.1. Other guidelines can in this particular case be found in earlier work that had similar views on education. This earlier work of Kortland and Vollebregt resulted in so-called didactical structures within a problem posing approach. (Both terms, didactical structure and problem posing, will be discussed extensively later.) Their didactical structures can be seen as designing aids for future similar approaches and were used as such in my design, which will be described in section 4.2.

4.1. View on teaching and learning

A view on teaching and learning to which I adhere, its relation to constructivism concerning both similarities and differences and the specific emphasis on problem posing has been described before (Vollebregt, 1998); (Kortland, 2001). For presenting my view in this thesis I will rely on an excerpt from an article from IJSE (2004) by Lijnse and Klaassen which I think puts the same matter clearly.

> "For the design of teaching sequences, e.g., in principle it may make a difference whether one starts from a receptive, behaviouristic, discovery or information-processing view on learning, to name just a few influential views from the recent past (Duit and Treagust 1998). Even though such differences may, in didactical practice, turn out to be much smaller than expected. Regarding views on learning, much attention has been drawn recently by constructivism. To our opinion, the didactical relevance of that view boils down to the rather trivial phrase that 'new knowledge is constructed on the basis of already existing knowledge' (Ogborn 1997). As such, this view does not relate directly to a view on teaching as the construction process of the learner takes always place, irrespective of how it is being taught. However, if one wants to prevent a learning process that results too quickly in a *forced* concept development full of misconceptions, or, in other words, if one adopts the view that teaching should result in something like real understanding, it seems necessary to allow students ample freedom to use and make their constructions explicit, e.g., by means of social interactions with the teacher and/or peers (freedom from below), and at the same time to carefully guide their construction process in such a way that it results in the aims that one wants to reach (guidance from above).
>
> Finding an adequate balance between this necessary freedom from below and the equally necessary guidance from above lies at the heart of our didactical research. It means that one tries to guide students in a *bottom-up*

teaching/learning process, starting from *common ground* (i.e. starting from shared, and known to be shared, ways of thinking about the world), by designing teaching activities that are to gradually create places in students' conceptual apparatus for the concepts and skills one wants to teach to occupy. In that sense, we can give content to the phrase 'construct new knowledge on the basis of already existing knowledge'.

At first sight, this view seems to represent nothing new, as is clear from many reports about 'constructivist science teaching' (Scott, Asoko and Driver 1992; Leach and Scott 2002). In our work, however, we differ in two major aspects from these reports. Though we take 'educational constructivism' in the above sense as a first starting point, we do not adhere to the 'alternative framework' movement. In our view, students' beliefs about their experiential world are, in general, largely correct, which implies that, if properly interpreted, we can always find common ground to start from in our teaching process (Klaassen 1995; Klaassen and Lijnse 1996). As far as cognitive learning is concerned, we think it best to think of science learning as a process in which students, by drawing on their existing conceptual resources, experiential base and belief system, come to *add* to those (with accompanying changes of meaning).

What we think needs to be added to this picture, as a second starting point, is that if this process is to make sense to them, students must also be made to *want* to add to those. Or, in other words, students should at any time during the process of teaching and learning see *the point* of what they are doing[9]. If that is the case, the process of teaching and learning will probably make (more) sense to them and it then becomes more probable that they will construct or accommodate new knowledge on grounds that they themselves understand. An approach to science education that explicitly aims at this, we call *problem posing*. The emphasis of a problem posing approach is thus on bringing students in such a position that they themselves come to see the *point* of extending their existing conceptual knowledge, experiences and belief system in a certain

[9] The following quotation, as reported by Gunstone (1992), shows that this is not a self-evident condition.

"In the following typical example, the student (P) has been asked by the interviewer (O) about the purpose of the activity they have just completed.

P: *He talked about it……..That's about all…..*

O: *What have you decided it [the activity] is all about?*

P: *I dunno, I never really thought about it …. just doing it – doing what it says … its 8.5 …. just got to do different numbers and the next one we have to do is this [points in text to 8.6]."*

In addition Gunstone (1992) writes: "This problem of students not knowing the purpose(s) of what they are doing, even when they have been told, is perfectly familiar to any of us who have spent time teaching. The real issue is why the problem is so common and why it is very hard to avoid". As a remedy, much emphasis has been laid on fostering students' general meta-cognitive knowledge and skills. Students should learn to learn. Without wanting to argue about the value of this emphasis, in our approach we adopt the additional view that it should also be clear to students on content-related grounds why and what they are doing.

direction. Thus formulated, also the second starting point seems rather trivial, and indeed it is. Since in themselves both starting points do not give any further detailed didactical guidance, the real *non-trivial* didactical challenge lies, as already mentioned, in the quality with which they can be put into practice. The more so as such an approach asks for a considerable change in didactical contract (Tiberghien 2000) as compared to what teachers and students are mostly used to.

In correspondence to this and in analogy to what Freudenthal (1991) writes about mathematics, we may say that we see science as a human activity and that, consequently, science teaching should guide students in '*scientificalising*' their world, instead of trying to transfer scientific knowledge as a ready made product. Freudenthal speaks in this context about a process of *guided re*invention that students have to participate in, adding that for its design it might be quite inspiring to look into the history of invention.

Our point of view of developing a problem posing teaching-learning approach along these lines thus asks for a thorough didactical analysis of common sense and scientific knowledge, as well as of their relation. How can we design a conceptual teaching pathway that is divided in such steps that, in a teaching situation, students are meaningfully able and willing to take them, building productively on what they already know and are able to? Can we make students ask or value questions that on the one hand make sense to them and that, on the other, ask for the development of (possibly adapted) new ideas and scientific concepts to be taught that provide an answer to their questions?

That means that, for them, the concepts to be reinvented will function for a particular purpose, and that the reasons for their construction and acceptance are directly derived from that functioning. In doing so, apart from being guided, knowledge construction within this problem posing approach is, in a sense, similar to the process of professional knowledge construction within science itself. Knowledge is (guidedly) constructed for a certain purpose. And it is accepted by those who construct it to the extent that it functions productively for that purpose" (Lijnse & Klaassen, 2004).

4.2. Use of earlier problem posing designs

Since it is my aim to develop a problem posing educational design it seems worthwhile to explore earlier designs with the same aim and see how these might become useful. The work of Vollebregt (1998) involved designing a problem posing course in an initial particle model. Since this topic is quite similar to mechanics in the respect that both aim for quite theoretical goals this seems a promising starting point to explore its possible use for designing a problem posing course on mechanics. It will turn out that this leads to the identification of four main themes in my design. I will first describe how these themes surfaced and then turn to some other use earlier problem posing designs had.

Four main themes

First main theme

One of the problems that need to be solved in a problem posing approach concerns the introduction of the topic. In my opinion each introduction should give students some sense of the importance and of the content of the subject to be learned. In other words an introduction should answer two questions: 'what is the topic about?' and 'why would I engage in it?' Taking this function of an introduction of any theoretical topic seriously results in a paradox[10]. How can one meaningfully indicate what a topic is about before starting it? One could of course take the introductory function not seriously and simply state what the topic is about, without considering whether this could be understood. For instance the topic of mechanics can be introduced by stating that 'mechanics is very important, it is about the three laws of Newton, the concept of force and mass et cetera'. Such an introduction does not give any understandable clue what mechanics is about to someone who does not know what the three laws of Newton are and what mass or force is. At the most it indicates which new words can be expected to get some meaning along the way. From a problem posing perspective this way of (not) dealing with the paradox is undesirable, for it does not provide the students with a motive or reason to engage in the topic and does not give any direction in what the problem with explaining motion might be, or how it might be solved, answered or explored. In terms of a problem posing approach dealing with this paradox can be expressed as finding a broad motive. This is particularly hard for theoretical topics, since the goal of understanding a particular theoretical topic (to the extent that it can provide some direction in how to engage in it) is more difficult to imagine at the start than a more practical goal (see also the last footnote). Vollebregt encountered this difficulty when she indicated that she did not succeed well enough in establishing an answer to the why- and what-questions in the introduction of her course on particle models.

Let us look in slightly more detail to Vollebregt's ideas about the why- and what-questions, since these served as inspirations for the design of my introductory course on mechanics.

Vollebregt identified the importance of addressing the why-question and attempted to do that by appealing to an assumed intrinsic theoretical curiosity in pre-university students and showing that it can be worthwhile to pursue knowledge of an ever more general kind. "This more general knowledge may allow for understanding why previous (less general) regularities are as they are and, moreover, may be used to explain and predict more events in a better way" (Vollebregt, 1998). However, she was not content with this part of her design. "[A] real motive for the introduction of a specific particle model is still missing, and therefore initial activities cannot sufficiently induce a theoretical orientation." This expectation was later, in the test of the design, observed to be true. In the discussion of her findings she suggests that a possibly more fruitful approach may lie in a general introduction consisting of a historical account of famous

[10] In the case of practical topics there need not result a paradox. Take for instance the practical topic of learning to drive a car. Here the student can envisage right at the beginning a pretty clear picture of what it is she is going to learn, without knowing how to drive at that stage.

scientists, "in order to show that people have always thought about the origin of everything around them, have tried to classify matter and have tried to figure out how it all works and what it consists of. […] In this way, the teacher shows in general terms what is going to be the issue of the next lessons [i.e. answers the what-question; ASW] and meanwhile builds on a possibly existing curiosity of some of the pupils [i.e. answers the why-question; ASW]" (Vollebregt, 1998). In the case of my design for the introductory mechanics course this idea of a historical account to show the importance of explaining motion seems also useful.

Answering the what-question in Vollebregt's design took place in a procedural way: looking for better understanding of already established generalisations by searching for even more wide-ranging generalisations. In retrospect she was not fully content with this and would have liked to include a more content related answer to the what-question. For this she suggested that "pupils' attention needs to be focussed, from the start, […] on giving explanations in terms of the behaviour of constituting elements, which differs from the behaviour of the system as a whole," that is to say functional explanations. My research originated in the idea to appeal to basic intuitions in order to suggest a content related direction to answer the what-question. The explanatory scheme for motion may, for the topic of mechanics, provide for this.

Second main theme

Next Vollebregt introduced in her course an initial particle model that was right away acceptable to students since it could immediately explain some phenomena, although it was not motivated from a content related perspective (see above). Students then extended their knowledge by refining and adapting this initial model in order to explain even more phenomena. This part of the design did what it supposed to do and was therefore quite successful in that respect. A similar idea may be used in the case of the design of the mechanics course by letting students look for concrete explanations of motions as 'refinings' and applications (or specifications) of the explanatory scheme. Both Keplerian and Newtonian mechanics can be seen as particular specifications of the explanatory scheme as was seen in section 2.

Third main theme

In the design of Vollebregt students were expected to reflect on the nature of particle explanations and the process of modelling during and after the development of the model. For this the comparison of alternative explanatory frameworks (one in which the temperature is related to the speed of the particles and another in which the particles themselves become warmer or colder) was useful, because it triggered a discussion of the fruitfulness of these alternatives in which the nature of particle explanations naturally was addressed. Both the need for a reflection and the way to bring it about by comparison of alternative frameworks seem useful to adopt in the mechanics course. In my case, alternative 'refinings' or specifications of the explanatory scheme for motion.

Fourth main theme

Vollebregt made the structure in particle explanations explicit in order to facilitate subsequent study of particle models in topics or subjects like electricity, nuclear physics, chemistry et cetera. Her design ends with an outlook on subsequent particle models. She did not indicate how in these later topics use could be made of her course. In my case I will give some indications of how use can be made of the introductory course in the regular course in mechanics, since it aims to be *introductory*, that is, it should have some use for the regular course.

Recapitulating it can be said that the work of Vollebregt suggests three successive themes that need to be addressed in a problem posing design for my introductory course:

- The *why* and *how* of introducing the topic. The explanatory scheme for motion plays a role in the 'how'.
- Extending students' knowledge by detailing the explanatory scheme to arrive at empirically adequate models for explaining motion.
- Reflection on the knowledge developed so far and the method of working. This consists of an evaluation of models and *types* of models in the light of achieving broader applicability.

To these three themes I like to add a fourth:

- Preparation of and embedding in the regular course.

This last theme has understandably little emphasis in Vollebregt's work since her course was not designed to be an introduction.

Earlier didactical structures guiding the design

Apart from (in a way) prescribing successive themes a problem posing design should address, the work of Vollebregt was useful for my design in another respect. Use of so-called didactical structures had implications for thinking about my design. I will first say something about what didactical structures are and then indicate what implications these structures had for my design.

A didactical structure of a topic is a functional description of the main steps in teaching/learning the topic. Both the work of Vollebregt and the not further discussed work of Kortland (2001) resulted in didactical structures. To make clearer what is meant by didactical structure let us take as an example the graphically represented didactical structure of the education designed by Vollebregt, see Figure 1. The point I want to make here is the use of structural elements, not the precise content of these elements in her course.

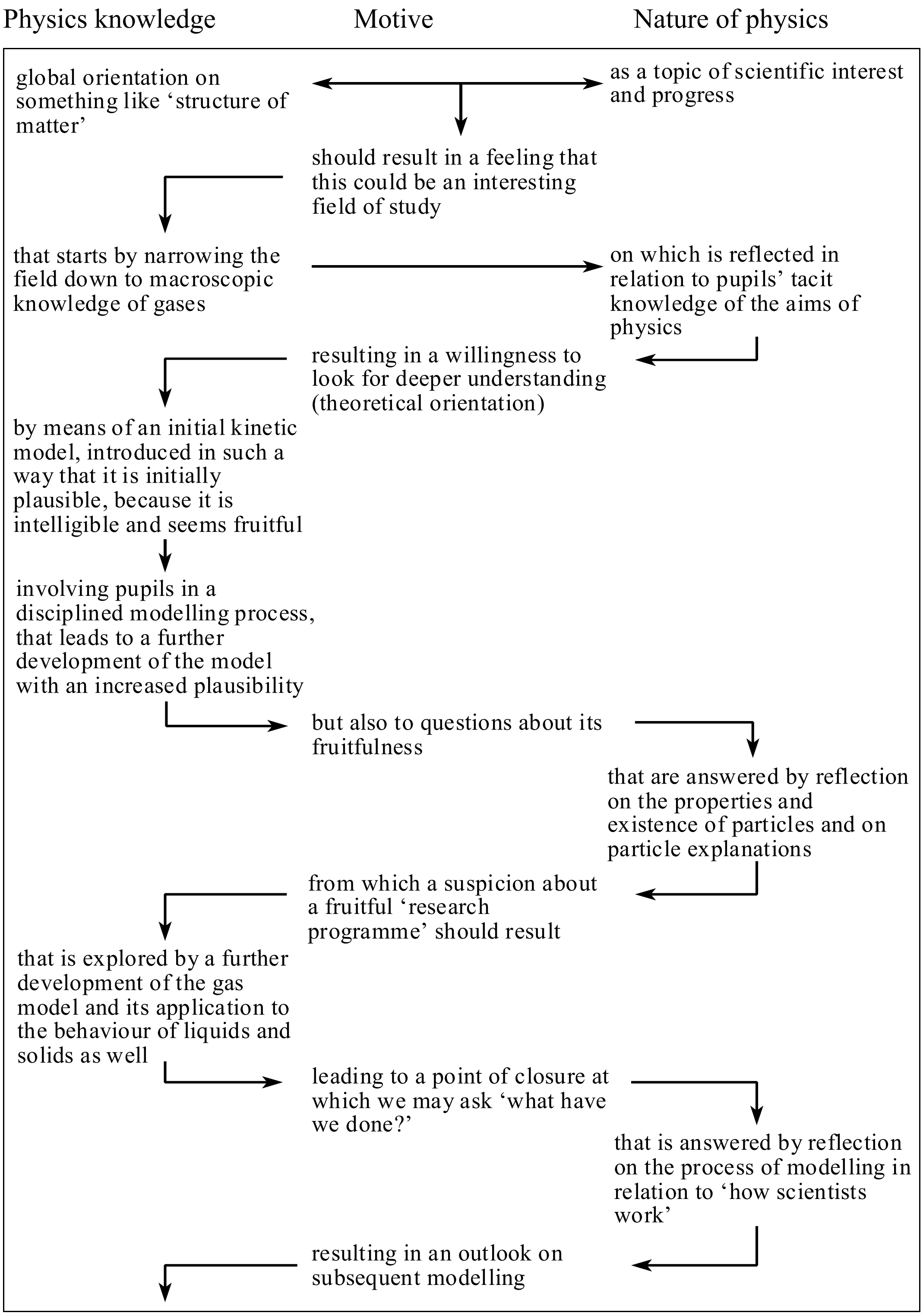

Figure 1: A didactical structure for a problem posing approach to the introduction of a particle model.

This figure shows a sequence of steps each with a specific didactical function that is organised in three columns. In the column on the left those steps mainly related to the educational goal of learning about particle models can be found. On the right one finds the steps related to a second educational goal about learning about the nature of particle models. These two goals were the main goals in this course. The column in the middle explicitly mentions the motives for the subsequent steps. One can see in a glance how each step is supposed to result in a (local) motive for the students to engage in the next step, which in turn results in a new motive et cetera. This figure also shows that aiming for two educational goals at once can become useful, for taking a step in the direction of one goal can provide for a motive to continue with the second goal and vice versa.

This kind of didactical structure had two implications for my design. Firstly thinking about the didactical structure was helpful because it made clearer what the main learning processes of the designed course were and secondly it forced me to make motives explicit. Let me explain. In thinking about the didactical structure of my design, with the example of Vollebregt's at hand, two questions were raised and answered. Firstly, what are the column headings in the depiction of the didactical structure? This question sounds trivial but behind it lies an important point, namely what the main learning processes related to the main educational goals are. In my case it was difficult to determine exactly which processes were coupled, if any. One candidate was (perhaps inspired by the didactical structure of Kortland) content vs. skill. Content could be regarded to consist of knowledge about the explanatory scheme and Newton's laws. Skills involved could be modelling and, arguably, applying the explanatory scheme. Another candidate was a coupling of physics and history. Historical topics about philosophy of change and movement, the study of heavenly bodies and historical persons like Kepler and Newton are used to get the physics across. However, it seemed more natural to view the history only as a context for the physics than as two separate and coupled learning processes. The third candidate was content vs. meta-content. In this case the content is knowledge about Newton's laws. Meta-content is thinking about the knowledge about Newton's laws, which includes the explanatory scheme. This last candidate was the most promising because it captured more fully the learning processes leading to the two educational aims of understanding (the conceptual structure of) mechanics and developing some appreciation for its power and range. The modelling mentioned in the first candidate seemed to be more of a secondary nature.

A second question raised by thinking about the didactical structure concerned the motives in between the successive didactical functions. Dividing the course in successive didactical functions forces one to think what the functional units are and if and how they logically (i.e. meaningfully for students) follow one another. A strong indication for the latter is whether explicit motives can be identified. Filling in a figure depicting the didactical structure can serve as a check for possible omissions in the design. If a particular motive is absent in the design, some justification for its absence is required.

In the next chapter the results of this thought process are presented in the form of a didactical structure and further description of the first design.

5. Summary

In this chapter backgrounds of the design of an introductory course in mechanics were addressed: the explanatory scheme, theoretical guidelines for the design and how the design will be developed which is expressed in the research method. The first included an extensive discussion of the explanatory scheme in which it was argued that this scheme underlying both Newtonian and common sense explanations of motion is a special case of causal explanation in general, which was meant to provide it with a solid backbone[11]. It was then argued that the explanatory scheme might function in mechanics teaching for which two necessary conditions were identified: (1) Students' use of the scheme needed to be triggered and explicated and (2) Newton's use of the scheme needed to be made explicit. Since the first condition was surrounded by much uncertainty as to how this might be done, a pilot study was undertaken to explore this question. This resulted in a feasible approach using video fragments to trigger explanations of motions in which students' use of the explanatory scheme could then be pointed out to them in a way that seemed quite natural to them.

After the notion of an explanatory scheme for motion had been firmly put on the map in this way the research question could be formulated as: 'How can the idea of a common explanatory scheme for motion in common sense and Newtonian mechanics be made productive in teaching/learning mechanics.'

This design question will be explored using the method of a 'design experiment', which involves a cyclic process of designing, testing and revising a prototype. In order to make the didactical quality of the prototype object of study detailed qualitative data of the actual teaching/learning process need to be collected and compared with an equally detailed description and justification of the expected teaching/learning process in the scenario.

Theoretical guidelines for the design were expressed in my view on teaching and learning, which involves the notion of problem posing education, and use of earlier designs starting from a similar perspective. Here the work of Vollebregt served as an important inspiration both in suggesting several main themes in my design and providing for the designing aid of 'didactical structures'.

[11] The criticaster that denies that the scheme functions in explanations of motion would now have to account for how causal explanations must be understood, since her denial of the explanatory scheme implicitly denies widespread notions about how causal explanations work.