Chapter 4

Development from first to second design

"Failure is the pillar of success, if you learn from it"

- Saying, popular in Sikkim on signs along the road

1. Introduction

Aims of this chapter are to present the second design on a broad level and to show (on this broad level) how the first design contributed to the second design. The latter illustrates the method of design experiments and provides for some empirical justification of (parts of) the second design. Although the first design turned out to be unsuccessful in many respects, still some important ideas developed from the first trial that were incorporated in the second design. For understanding these ideas a broad description of the development in the design suffices. In fact a more detailed description and analysis of the first trial would not be useful given the numerous flaws in that design.

The design can be viewed from several perspectives ranging from more broad to more detailed. The broadest perspective concerns the four main themes already introduced in chapter 3:

- The why and how of explaining motion. The explanatory scheme plays a role in the 'how'.
- Extending students' knowledge by detailing the explanatory scheme to arrive at empirically adequate models for explaining planetary motion.
- Evaluation of models and types of model in the light of achieving broader applicability.
- Embedding in the regular mechanics course.

Zooming in, each main theme can be divided in several episodes. An episode is a sequence of connected activities related to a particular goal. An episode forms a coherent unit in a lesson in the sense that it requires an introduction, after which some activities addressing some central question follow, and is finally evaluated in light of the introduction. Its size ranges from 30 - 80 minutes.

The most detailed perspective on the designed course is a description of its activities, like answering questions, reading texts or listening to an explanation by the teacher, in which the description concerns the actual questions, texts or formulation of the explanation. Perhaps a time frame may make this distinction clearer, see Table 1:

Zoom size	Describes	Time frame	Relevant sections
Broad	Main themes	lessons	chapter 4, section 2
Intermediary	Episodes	30 - 80 minutes	chapter 5, section 2
Detailed	Activities	1 - 10 minutes	chapter 5, section 3 - 5

Table 1: Different levels of description

The content of the first design, the development in the content from first to second design and the second design will be described on a broad level for the first three main themes in section 2. In this description sometimes some details are mentioned for the sake of clarifying the description on the broad level. The fourth main theme will be addressed slightly differently because it was not put to the test to the same extent as were the first three main themes. It will be described on a broad level and will not include a discussion of how results from the first trial led to revisions in the design of the second.

The development in the teacher preparation from the first to the second design will be described in section 3. The preparation of the teacher in the first trial led to the idea of using interaction structures for the preparation of the second teacher. What this idea entails and how it was put to the test will be the topic of this section.

This chapter will give the reader a rather general view of the revised design. In chapter 5 I will further zoom in on the design by first presenting an overview of the related episodes and then describing the episodes in detail, that is on an activity level.

Let me begin with some remarks concerning the research method used in the first trial. In the first trial one teacher and one pre-university level class of 27 sixteen year old students (Dutch: 4 VWO) participated. This teacher agreed to spent ten 50-minute lessons on this experiment, which consisted of about one quarter of the time he would see this class in that year. The willingness of the teacher to participate in this project, which was also due to that he was a former colleague of mine, was the main criterion for selection. It was an ordinary class in an ordinary school with an ordinary teacher. Teacher explanations to the whole class were video taped. Group discussions were audio taped. I selected four different groups each lesson. Groups ranged in size from two to five students depending on the activity. The teacher and researcher carried a tape recorder all the time, recording all interactions. Students' written materials were photocopied after each lesson.

Based on data obtained in these ways I compared the intended teaching/learning process to the actual one. This analysis did not delve very deep, since the findings at a more superficial (or broader) level already indicated some shortcomings and already suggested ways of improvement. This is a rather normal feature of this kind of research where, although one spends considerable time and thought on the first prototype from behind one's desk, it still shows considerable design flaws when put to the test. Fortunately such a test also gives ideas for improvement. I will present here only the design and results from its test on a broad level, which should suffice to understand and follow the changes made in the second design.

2. The content from first to second design

In this section I will describe the development from the first design I tested to the second design, and organise this description around the four main themes. The development within each theme will be addressed in the four following subsections, starting with the first: The *how* and *why* of explaining motions. This includes a description of the first design, the main results that led to revisions in this design and a description of the resultant second design. The fourth main theme will be described slightly differently, as was already mentioned in section 1.

2.1. The *how* and *why* of explaining motions.

I will first describe, in section 2.1.1, how the first design was expected to implement the functions of the first main theme. Then, in section 2.1.2, I will present some results of testing this design that lead to revising this first design. Finally, in section 2.1.3, I will describe the second design in light of these results. (This procedure is then two times repeated for the second and third main theme in the subsequent sections.)

2.1.1. First design

In the first main theme I tried to develop a theoretical orientation towards explaining motion. This main theme is concerned with the questions '*why* study the topic of explaining motions' and '*how* are motions explained'. In the first design this was implemented in a way that is depicted in Figure 1.

Physics	Motive	Reflection on physics
Orienting and evoking a broad interest in and motive for a study of change as a phenomenon and philosophical theme. Orientation on the course.		
	Should result in the notion that this is an important and interesting theme worth knowing more about	
starting with movements and their causes	→	on which by reflection an underlying scheme is found and made explicit, in relation to history
	resulting in a willingness to look for deeper understanding (theoretical orientation)	←

Figure 1: Didactical structure of the first main theme in the first design.

The question '*why* study explaining motions' could be answered by pointing out its importance as an essential part of understanding the larger theme of change as a phenomenon and philosophical idea. After starting with the big theme 'change' as broad motive, the plan was to narrow it down to the more specific motive of understanding motion by the argument that understanding motion is an important part of understanding change. The theme 'change' could be introduced by means of several philosophers expressing, each in their particular way, how they understood change in terms of the motion and interaction of particles. These positions could then be illustrated with the example of how they would explain the freezing of water. The role of the teacher in this was crucial for instilling a sense of wonder and curiosity. I expected that not so much what was said, but the enthusiasm with which it was said would trigger student's dormant curiosity.

The plan was to answer the question *how* motions are explained with the explanatory scheme, that for that reason needed to be triggered and explicated. Students should come to notice that different explanations of various motions have something in common, namely that influences can be identified and that those influences cause deviations from influence free motions. In order to appreciate the explanatory scheme students need to be oriented towards its theoretical use for understanding all explanations of all motions. This theoretical orientation in a student is an attitude that abandons specific practical aims and interests in explaining a motion and should result in a willingness to look for deeper understanding.

I expected that the recognition of plausible influences and a particular type of motion as influence free is easiest in relation to the ways we ourselves influence motion, see also chapter 3 section 2.1. That is, if standing still or gradually coming to a stop are taken as influence free, various kinds of actions we can perform can be related to kinds of deviations from the assumed influence free motion. In chapter 3 section 2.3 I called these actions 'personal influences'. In other cases involving 'non-personal influences', these influences are less easily recognised precisely because an assumption for an influence free motion in combination with a plausible interaction theory to account for deviations from it is lacking. With 'interaction theory' I mean notions concerning the causes and effects of influences that can range from vague (or even implicit) regularities between causal factors and their effects on the motion to precise (and explicit) force laws like Newton's law of gravitation.

In order to trigger and explicate the explanatory scheme the plan was to examine some explanations of motion in which use of the scheme could be pointed out. A way of triggering explanations of motion used in the first design was using video fragments of motions that were stopped after which the students had to predict and explain the continuation of the interrupted motions. This approach was tested in a pilot study that was described in chapter 3 section 2.3, which started with motions involving only personal influences and later including also non-personal influences. In that pilot it was seen that in the explanations of the motions students watched they mentioned things that I would call influences on the motion. These influences had to be operating because otherwise the object would move differently, namely according to its assumed influence free motion. This general argument of the explanatory scheme, also used (implicitly) by the students was then pointed out to them.

The role of the teacher in triggering and explicating the explanatory scheme is a difficult one. He has to use the diverse student responses recognisably, ensure that the details of the explanatory scheme surface clearly while retaining perspective on the purpose of arriving at an understanding of what explaining motion is about.

This was the first general plan for evoking a broad motive (understanding change) and narrowing this down to a content specific motive (understanding explaining motions) for which students need to adopt a theoretical orientation. This plan was further worked into a concrete design and tested in the first test round. This first main theme took about two 50-minute lessons. I will now discuss some results from this test that lead to revisions of the design.

2.1.2. Results leading to revision of the first design

The execution of the design deviated from the plan in the sense that the supposedly enthusiastic introduction was simply read out and contained irrelevant mentioning of the September 11th disaster, which did raise interest, but for the wrong reasons and the evaluation of the assignments from which the explanatory scheme should have been clearly explicated was almost completely lacking. Although this made it more difficult to draw conclusions about the effectiveness of the design, still some points worth mentioning surfaced.

The first introductory function of answering the question '*why* study mechanics' did not work well enough. The problem was that although the notion of building blocks of matter was caught on to, the essential next step that change can be understood in terms of the motion and interaction of these building blocks was not. A possible cause might have been the following. The chosen example (of freezing of water) and terms that were used could have invoked an image of a 'static change'. That is to say some state before, then a change and finally a state after, where the dominant aspects are the state before and after and the importance of the change in the middle remains unclear. For instance when asked to write down some similarities and differences between the studied philosophers a student wrote down:

> "Similarities: Changes are achieved by arrangement of matter. In arranging the particles are mixed. After the arranging the particles returned in another way.
>
> Differences: Other notion on how particles were arranged."

The word 'arrangement' was used in the student material, which was unfortunate since it has a static connotation.

That students did not see the function of the start concerning the 'change as motion' theme was confirmed later in the course. Students drew conclusions in the third main theme in an essay assignment (assignment 26, which will be described in section 2.3.1). They made an effort in writing these essays, which can be considered to reflect what students thought were the salient parts of the introductory course, as well as what they have understood from it.

Let me begin by summarising the findings from these essays and then present a complete account of all relevant statements from the essays related to how motion is explained. Students mentioned those elements from the course they considered to be necessary for predicting (or explaining) motion. They varied in amount and type of elements that were mentioned. Although only two students (Els and Michael) explicitly mentioned the explanatory scheme, all students implicitly made use of the scheme in explaining motion. What is interesting and also in a way reassuring is the diversity in elements that were mentioned. Apparently all the necessary ingredients for an explanation of motion can be recognised by students in the course. There were some who have understood, at least to the extent of finding it important enough to mention it in a recapitulating essay, the importance of an influence law, some the rule deviation = influence/laziness and some the assumption for an influence free motion. Students were not asked to write (elements of) the explanatory scheme down. They were asked to write what explaining motion is about. That they did mention these elements indicates their viability, which I find reassuring.

When writing about how motions are explained some students expressed elements of the explanatory scheme or sometimes tried a general description like the one from the student booklet.

> Els: Explanatory scheme for motion:
> 1. An assumption for the influence free motion.
> 2. Deviations from that influence free motion can be explained by identifying suitable infleunces.

This does not necessarily mean Els has understood it, but at least she considered it important enough to include it in her essay.

Sometimes students mentioned the three elements of the scheme identified in the following figure from the student booklet (§1.6.2, p. 16), which was copied by two students (Rachel, Stan) or described in words by three others (Abe, Tara, Koen)

Kepler	Newton
- Influence free motion is rest	- Influence free motion is straight motion with constant velocity
- deviation = influence / laziness	- deviation = influence / laziness
- Deviations can perhaps be explained by a dragging influence of the rotating sun (spoke explanation).	- Deviations can perhaps be explained by an attracting influence between all heavenly bodies amongst which the sun (gravitation).

Some only mentioned a single element from the scheme, namely the rule deviation = influence / laziness, but did not mention anything about influence laws (Bertine, Mathilde, Mark, Niek, Bashel, Iwan). Take for example Bertine and Iwan:

> Bertine: I have used the formula deviation = influence / laziness a lot.

> Iwan: To predict a motion one needs three things according to Kepler and Newton. Using these two things, the third is calculated. The first two one needs are influence and laziness. By dividing the influence by the laziness one gets the third. The third is deviation which shows how an object will move.

Six others did not mention this rule, but talked about the need for influence laws.

> Lisanne: I think you first have to know that [whether there are influences], in order to determine the motion of an object. One also has to make a formula or influence law. Then one can predict the motion of among others heavenly bodies.

> Emma D.: I found it difficult to correctly predict a motion, because I did not know which forces how strongly were operating on the object. I still don’t know that, which I think is a pity.

> Emma D. did not know which forces were operating and how strongly they affected the object. Apparently she does know that one should know these things, i.e. an influence law, in order to predict a motion.

> Nicky / Emma N.: In order to predict a motion one has to know how it originated, what is causing its progress, one also has to know the circumstances and which forces are 'busy'.

Although Nicky and Emma N. do not mention influence laws, knowing which forces are 'busy' implicitly signifies the same thing.

> Bertine: One could say one has completely understood a motion when one has made a prediction of how the motion will continue, and that turns out to be true. [...] One needs an influence law to predict a motion.

> Joffrey: To predict a motion one needs all properties that are required. One needs a formula. In that formula one has to fill in all those properties.

With properties Joffrey means influence-affecting factors, I think.

Some students mention the elements of influence (law) and rule. This was found in the essays of two students:

> Mathilde: When you want to predict a motion of an object, it is important to know the influences (like gravity), then you can predict the motion of the object. With the formula of Kepler and Newton.

> Els: I have learned how motion can be predicted using influence and the law of Newton and Kepler.

With 'the formula or law of Kepler and Newton' Mathilde and Els mean the rule deviation = influence / laziness, I think.

The most complete accounts of how motion is explained were given by Michael and Sophie.

> Michael: By this I learned what to do first in order to explain motion. Namely that you first ask yourself what would happen when there are no influences to be identified. This is called the influence free motion. In case deviations on the influence free motion occur, than that is caused by other influences. With these data an explanatory scheme was formulated. This was used in the notions of Kepler and Newton. They each had their own notion of the deviation from the influence free motion. This is also summarised in a scheme and an influence law according to Kepler and Newton was formulated. And with the help of that law I could predict motion.

Michael mentions all elements of the explanatory scheme, except the rule. Only the connection between the elements remains unclear.

> Sophie: According to the models of Kepler and Newton we can now predict the motion of objects and planets. By using the influence law one can determine the position of an object or planet when there is a particular influence working on it. The formula for this is: deviation = influence / laziness. Kepler says that with the influence free motion is rest. According to Newton the object without influence will go straight on with constant speed.

Sophie mentions all elements, but also in this example without their connection. This ends my presentation of these essays and I will return now to the functions of the introduction.

The second introductory function of answering the question *how* explaining motions work, expressed by the explanatory scheme took place too late and ineffectively.

It was too late in the sense that in the whole first lesson students had to discuss philosophers' ideas about change, without any sight of what this had to do with mechanics. For instance, some remarks students wrote down in response to the evaluative questionnaire after the whole introductory course indicated some confusion what this beginning had to do with anything.

> Niek: "In the beginning I really thought: What is this?";
> Tara: " In the beginning I did not understand well what the purpose of the course was, ...";
> Rachel: "In the beginning I found it difficult, and we did not go into the assignments that much in the lesson, the first part I did not understand entirely."

The second introductory function was ineffective in the sense that the video fragments triggered the expected type of responses, but pointing out the explanatory scheme in them in the intended way, that is in close connection to the student input, while managing a class discussion proved very difficult. The teacher had to manage a kind of class discussion (only student - teacher interaction, no student - student), check that sufficient responses were elicited, remember those responses and abstract those in terms of the explanatory scheme. That is a very difficult task that took me practice in several interviews before I could pull it off in interviews involving only 2 students. Let alone the difficulties involved in doing it in a class of 27 students without any practice! This would require a kind of preparation that did not occur. (How the teacher was prepared will be discussed in section 3.)

What could be seen in the explanations of the various video fragments was that personal influences were easily identified and their role in accounting for the motion was quite clear. Non-personal influences like gravity or friction could be triggered e.g. by comparing fragments and careful questioning, but making clear the function of these influences in accounting for the motion was more difficult. Without having already some interaction theory (however primitive) students found it difficult to identify an influence solely on the basis of accounting for the observed motion. Why was this so difficult? Explaining an observed motion in terms of a deviation from an assumed influence free motion, caused by some to be identified influence, can be compared with trying to solve two variables from one equation. The equation, which stands for the observed motion, is clear. However, when students are uncertain about what influence free motion to assume (one variable) and have almost no clue what influence (the second variable) may cause the deviation from such an influence free motion, this task will prove very difficult indeed. For instance, in the case of a ball moving in a circle with a gap none mentioned an influence of the tube on the ball, which I expected to happen for those students that predicted something else than a continuation of the circular motion when the ball reaches the gap. (If they did it that would have indicated an assumption of circular motion as influence free motion.) Discussing some influence for which they have no name (like 'influence of the tube' or 'centripetal influence') solely on the basis of the notion that some influence has to be there because the observed motion deviates from the assumed influence free motion was at this stage a 'bridge too far'. Even when they can name an influence its role in the explanatory scheme is hard to make explicit when they lack a sufficiently precise interaction theory. Recapitulating, it can be said that the difficulty lies in that students were asked to apply the explanatory scheme that had been explicated from their explanations of motions involving only personal influences directly to motions including also non-personal influences.

2.1.3. Second design

The problems that arose in performing the function of the introduction, discussed in section 2.1.2, resulted in two revisions of the design. Firstly explaining in general will be used as a stepping-stone for explaining motion. Secondly the course will start with the topic of motion directly, instead of introducing it as a special case of change. I will now discuss what these revisions entail and how they are supposed to remedy the problems of the first design.

Improving the design by means of a general explanatory scheme

In the first design I attempted to show what explaining motions in a general way is by explicating the way students already explain motions involving only personal influences and by letting them apply this to motions involving also non-personal influences. However, this proved to be difficult and did not succeed well enough, as was seen in the previous section. A solution to this problem may be found in the idea that explanation of motion is a special case of causal explanation (see chapter 3, section 2). If it is possible to trigger the structure in causal explanation in general, this structure (or general explanatory scheme) can be used as a stepping-stone to the explanatory scheme of motion. The idea is that the general explanatory scheme can be expected to be quite easily triggered, e.g. in the way described shortly. The explanatory scheme for motion could then be introduced as a special case of the general explanatory scheme. Next it could be applied to motions involving mainly personal influences, which is expected to be easy as results from the test of the first design indicated. Explaining motions can then be explicated as filling in the explanatory scheme. This filling in of the explanatory scheme can then be applied to the more difficult motions involving also non-personal influences. I did not know to what extent students were able to take this last step, which is one of the reasons to try this out in a second pilot study, which took place after the first trial and before the second trial (see Table 2). In the first trial the explanatory scheme for motion was explicated on the basis of motions involving personal influences and applied (which failed) to other motions. In the suggested revision the explanatory scheme for motion is already explicated by means of the general explanatory scheme and applied (which is expected to be successful) to motions involving personal influences.

Research activity	When?	What about?
Pilot 1	Summer 2001	Triggering and explicating the explanatory scheme for motion by means of video fragments
Trial 1	Winter 2001	Test of first design
Pilot 2	Winter 2002	Triggering and explicating the explanatory scheme for motion by using the general explanatory scheme as stepping-stone
Trial 2	Spring 2003	Test of second design

Table 2: Sequence of research activities

How can the structure in causal explanation as presented in chapter 3 section 2.1 be made productive? In chapter 3 we saw that 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 background to make the occurrence of the event intelligible. This can be made clear to students by explicitly comparing the event and the assumed background. The following depiction of an explanation of sugar slowly dissolving in tea, 'the sugar dissolved slowly in the tea, because the tea was not stirred' can be helpful for this comparison (see Figure 2).

Situation A Slowly dissolving	Situation B Quickly dissolving

- No stirring	- Stirring
- Tea	- Tea
- Sugar lump	- Sugar lump
- Temperature T	- Temperature T

Regularity: Always when tea is stirred, sugar dissolves more quickly then when it is not stirred, all other things being equal

Figure 2: General explanatory scheme applied to the example of dissolving sugar in tea

This figure shows a completed or filled in depiction of this explanation. In this case the sugar is considered to be slowly dissolving because the tea was not stirred. The event to be explained, depicted on the left, is mentally compared to the background, which is a situation in which the sugar dissolves more quickly, because in that case the tea is stirred, depicted on the right. What needs to be added to this background to make the occurrence of the event intelligible is the absence of stirring, which is a somewhat awkward way of saying that the stirring needs to be taken away from the background to account for the event of slowly dissolving sugar. The background can be characterised by numerous factors like the amount and sort of tea, the amount and shape of the sugar lump, the kind of sugar, the temperature et cetera, that are the same for both situations.

Furthermore in chapter 3 we saw that 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. In the given example the explanation makes implicit use of the regularity or lawlike generalisation ‘always when tea is stirred, sugar dissolves more quickly than when it is not stirred, all other things being equal’. In this way such depictions can become a useful tool to talk about the general structure in causal explanations in a way that is not as abstract as the discussion in chapter 3, but is expected to be concrete and easily recognisable for students. As indicated in chapter 3, section 2.3, with respect to the explanatory scheme for motion, I also assume with respect to the general explanatory scheme that students, like everybody else, make implicit use of it. The serious problem is how to make them recognise and explicitly use the structure in their causal explanations.

Students may be guided by several questions in filling in such figures themselves. With the help of this depiction the general structure in one explanation could be pointed out. Students can then be asked to fill in elements of depictions of other explanations, but with almost all text left out, to see if they understand the different elements of the general explanatory scheme and how they are related.

It can then be pointed out that explanations of motion can be seen in a similar way. For instance students could be asked to identify several elements of an explanation of a particular motion involving only personal influences with the help of a similar depiction as the sugar dissolution explanations, see Figure 3.

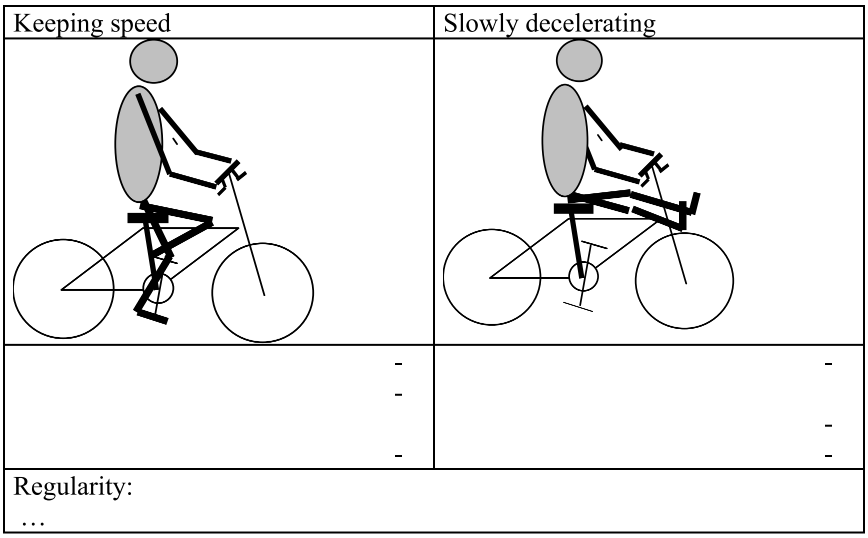

Figure 3: Comparison bicycle riders 1

Here also two situations differ in one relevant factor. In this case the influence pedalling can be identified, while many factors that characterise the background are the same: the person cycling, the bike, the surface, the tension in the tires et cetera. The pedalling can be related to the phenomenon of keeping speed by the regularity 'always when one (steadily) pedals, one is keeping speed, all other things being equal'. From this the explanatory scheme for motion can be explicated as a special case of the general explanatory scheme. The students can then be asked to apply this scheme in explaining another motion involving also non-personal influences, to see to what extent they had understood it.

This way of depicting the explanatory scheme for motion was inspired by the similar way of depicting the general explanatory scheme. The obvious similarities in presentation are expected to help students see the similarities between both schemes themselves.

A concrete implementation of the idea of using the general explanatory scheme as stepping-stone was tested in a second pilot study to see whether such an introduction was in fact easier. Another question in this study was whether the students recognise the similarities between the general explanatory scheme and the explanatory scheme of motion. Seeing the similarities is an important prerequisite for this idea to work. The similarities can be emphasised[1] by addressing and using both schemes in the same way, e.g. by using the same kind of depictions of the scheme. I will now describe the method and results of this second pilot study and then return to the main point of the first part of this section, improving the design by using the general explanatory scheme as a stepping-stone, in the discussion of the results of this pilot.

<u>Method of the second pilot study</u>

The idea of a general explanatory scheme was worked into an educational design. Students were presented with several explanations of sugar dissolving in tea, one of which was depicted in the manner of Figure 2. This design was tested in a quasi-educational setting with the researcher as teacher and two students as class, which can also be seen as a structured interview. The research method of the second pilot study was similar to the first pilot study described in chapter 3 section 2.3. The first couple of interviews (about four) served as try-out for the interview scheme, which during this phase was adjusted until it seemed 'good enough'. The subsequent interviews all followed the same interview scheme and were for data gathering. Saturation effects determined the amount of interviews held. If new interviews were no longer surprising it was time to stop (which happened after about 8 interviews, including the try-outs).

The interview was described in a scenario-like interview scheme, together with a description of the intended teaching/learning process with argued expectations and how this is supposed to contribute to answering the research questions of this second pilot study.

<u>Results of the second pilot study</u>

[1] Since both schemes *are* very much alike, as was shown in chapter 3, using them in a similar way would be a very natural thing to do. In this sense it would be not entirely correct to speak of *emphasising* the similarities. The similarities are obvious, but still have to be shown.

The interview with the students seemed to work as intended, but up to a certain point. The general explanatory scheme could be pointed out to them with the help of the example of sugar dissolving in tea. The transition to explanation of motion could be made, in which students appeared to see the similarities between both explanatory schemes. Also pointing out the explanatory scheme for motion in explanations concerning only personal influences went well. Applying the scheme to other motions, for which also non-personal influences were needed, proved to be very difficult. Students were able to mention a couple of other factors, which may influence a motion apart from personal influences. Some students expressed their intuitions concerning an influence free motion. As expected they were less sure about what a motion without any influences would look like than what it would look like without personal influences. However, in pointing out the connection between the (assumption of an) influence free motion and identified influences I lost them. Students, having understood the explanatory scheme for motion in the case of only personal influences and realising that only personal influences are not enough for a complete explanation of motion, could not extend the explanatory scheme for motions to include all influences by themselves.

<u>Discussion of the second pilot study and implications for the course design</u>

That students could not extend the explanatory scheme for motions to include all influences is in retrospect not surprising. I think two factors account for this: lack of purpose and lack of sufficiently precise interaction theory in combination with an assumption for an influence free motion. The latter was discussed before. It is difficult to apply the explanatory scheme for motion without having a proper interaction theory in combination with an assumption for an influence free motion. At this stage and in this way students cannot be asked to do this by themselves.

It gradually dawned upon me, however, that this difficulty may be a blessing in disguise. ("It’s not a bug, it’s a feature!") The problem of extending the scheme to include all influences may be used constructively to guide subsequent activities. That is, whereas the process of filling in the explanatory scheme for motion including non-personal influences will remain as difficult as it was for the reasons already indicated, this experienced difficulty need not be disastrous. Rather, overcoming this difficulty will indicate precisely the direction which the students will have to take in the subsequent parts of the course, namely finding a proper assumption for an influence free motion in combination with a proper influence law for the environmental influences involved. As was mentioned before, students did get a sense of the ‘unextended’ explanatory scheme for motions in the interviews. They can therefore be expected to understand that they need to know more about the elements of the scheme in order to explain (in theory) all motions. They also have to want this of course, which brings us back to the first mentioned factor: the lack of purpose.

In the interviews students easily could have lost sight of (or had not got in the first place) the reason for viewing explanations of motion in this particular *theoretical* way. The point of the extension was to be able (in theory) to give a complete explanation of all motions. The reason that the students did not see this was that it was not made clear in the present design. That the interview was about a theoretical way of looking at explanations (of motions and in general) should have been made more explicit throughout the sequence as well as the reasons for adopting a theoretical perspective. There are several reasons that may be used in a new design to remedy this lack of purpose, for instance:

- The big philosophical picture of mechanicism, in which understanding motions, together with understanding building blocks (subject of another course) can lead (in principle if not in practice) to understanding and thereby predicting or controlling all material events.
- Plain curiosity. People just want to know how things work, sometimes in detail.
- Occasional practical relevance, for instance in predicting whether or not a meteor will collide with earth or in getting a satellite in orbit et cetera, in which also the theoretical perspective can be useful.

To recap: Explicating the explanatory scheme for motion by means of video fragments was seen to be promising (pilot 1), but also difficult (trial 1). The difficulty (apart from difficulties in the execution) was that the explanatory scheme for motion after being explicated from familiar motions, in which personal influences play a part, was applied to motions that were too difficult since they involved non-personal influences for which students lacked a proper assumption for an influence free motion in combination with sufficient interaction theory. A possible way out was to make use of a stepping-stone in the form of the general explanatory scheme. In that way the explanatory scheme for motion is explicated as a special case of the general explanatory scheme and then applied to a situation students *are* familiar with, namely motions involving personal influences. Although this made understanding the explanatory scheme for motion in the case of only personal influences easier, explicating the complete scheme remained difficult. It might appear that we have come full circle to the initial problem, but this is not the case. The difficulty itself has changed from a difficulty in applying the explanatory scheme to motions involving also non-personal influences to a missing perspective on the *theoretical* approach to explaining motions. The first thing is still difficult but serves another purpose: not as an essential part in explicating the scheme, but in providing a direction for subsequent activities and therefore ceases to be a problem. "It's not a bug, it's a feature!"

Improving the design by starting with motion directly

I already mentioned that the introductory function of answering the question '*why* study mechanics' did not work well enough, because its relation to motion did not become clear. In revising the design to improve it in this respect the idea of using change as overarching and recognisably important theme was not abandoned at first. To focus more on motion instead of building blocks another presentation of the mechanicism theme was considered, illustrated with another philosopher (Hobbes) and using a more dynamic (i.e. non static in the sense of initial state - change - final state) example.

However, the same function of answering the question 'why study mechanics' may more directly be performed in another way, namely with a suitable example of a motion. Such an example should be a motion of which it is clear that it would be important to be able to explain or predict it. This shows that there is at least one motion, and raises at least the suspicion that there may be more, that is important to explain and thereby gives some weight to the subject of explaining motions. Furthermore it should be theoretically challenging to explain it, that is, students should be unable to do it at the moment, but can see ways, however vague, to approach such a problem. In such a way the right theoretically oriented (physical) mindset can be evoked. This way of answering the why-question also enables one to move more quickly to the what-question. In my detailed description of the design in chapter 5 I will argue that the example of an asteroid moving towards earth may perform this function. The mechanicism approach of the first design may still fulfil a function in illustrating the range and scope of mechanics and thereby provide an additional answer to the question about the value of mechanics in main theme 3. It is therefore postponed to that stage of the course.

Outline of the first main theme in the second design

The described revisions led to the second design with a didactical structure that is depicted in Figure 4.

Mechanics	**Motive**	**Explanation**
Broad orientation on motions	→	that are worth predicting /explaining
	Should result in the notion that this is an important and interesting theme worth knowing more about	→
		Starting with explanation in general and explanation of motions in particular in which by reflection an underlying scheme is found and made explicit
	which should lead to the feeling that it is a theoretical challenge to explain motions by means of an as yet unknown specification of this underlying scheme (theoretical orientation)	←

Figure 4: Didactical structure of the first main theme in the second design

Note that the third column is now headed ‘explanation’ whereas it was headed ‘reflection on physics’ in the first design. The reason for this change was that the teaching/learning process depicted in the right column is better captured by how explaining works as a driving force for understanding how explaining motion works, which is the teaching/learning process depicted in the left column. The reader may recall that in chapter 3 section 4.2 one of the general uses didactical structures can have in thinking about educational designs was that they force one to think about what the main learning processes related to the main educational goals are, by means of the question ‘what are the column headings in the depiction of the didactical structure?’ Here we see an example of this use.

The function of the first main theme is still the same: It concerns the questions ‘*why* study the topic of explaining motions’ and ‘*how* are motions explained’, for which a theoretical orientation needs to be developed. The question ‘*why* study explaining motions’ is now answered by pointing out that there are motions that are important to predict and explain. This answer should result in the notion that this is an important and interesting theme worth knowing more about. The question ‘*how* motions are explained’ can be answered with the explanatory scheme for motion, which is introduced by using the general explanatory scheme as stepping-stone. In order to appreciate the explanatory scheme for motion students need to be oriented towards its theoretical use for understanding all kinds of motions. Before specific motions can be predicted and explained elements of the explanatory scheme for motion need to be specified in some way. How this is worked out in detail can be found in chapter 5 section 3.

2.2. Extending students’ knowledge by detailing the explanatory scheme to arrive at empirically adequate models for explaining planetary motion.

I will first describe, in section 2.2.1, how the first design was expected to implement the functions of the second main theme. Then, in section 2.2.2, I will present some results of testing this design that lead to revising this first design. Finally, in section 2.2.3, I will describe the second design in light of these results.

2.2.1. First design

In the second main theme students’ knowledge is extended, for which in the first main theme some willingness should have arisen and which should lead to questions concerning the fruitfulness of the used models, as depicted in Figure 5.

Physics	**Motive**	**Reflection on physics**
	resulting in a willingness to look for deeper understanding	
by means of the study of celestial mechanics in terms of models		
	resulting in a question concerning the fruitfulness of these models	

Figure 5: Didactical structure of the second main theme in the first design

The extension of knowledge consists of the preparation of basic notions of mechanics, like second law, first law, law of gravitation, concept of mass and inertia, by means of a study of Keplerian and Newtonian specifications of the explanatory scheme. For this the motions of heavenly bodies are modelled and criteria for good (enough) models like plausibility and empirical adequacy are (implicitly) used. In chapter 3 section 2.2 I argued for the usefulness of the context of heavenly bodies as well as the choice for both Kepler and Newton. The subsequent question concerning the fruitfulness of these types of models is expected to naturally surface in the process of investigating models by comparing alternative types, i.e. Keplerian and Newtonian models. These will be discussed in section 2.3.

The study of celestial mechanics can be considered too difficult for 16-year-old students, since they cannot determine the motion analytically given some force law (neither can many a physicist), because of the mathematical complexities. However, numerical solutions as acquired by means of computer models can become very useful here. I have tried to give students some feeling for the workings of a computer model that calculates the motion of celestial objects, given some influence law. The method of graphically constructing motions, as used by Newton, served as an inspiration in this matter, see Figure 6.

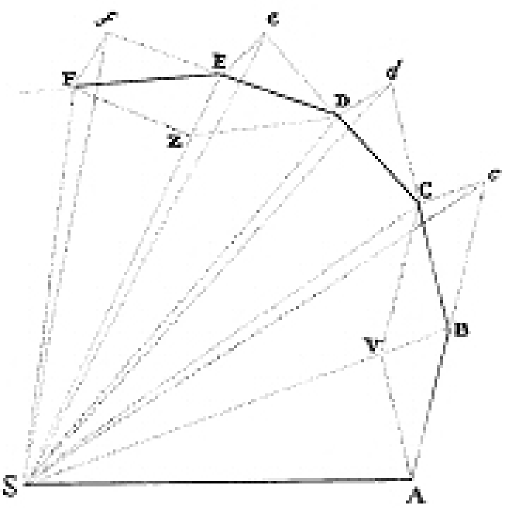

Figure 6: Drawing used by Newton in the Principia in his proof of Kepler's law of equal areas

I merely want to draw attention to how this construction embodies the explanatory scheme for motion. Suppose that in a small period of time an object moves from A to B. In the absence of an influence it would in the next period move straight ahead with the same speed (Newton's assumption for the influence free motion) and arrive at c. Instead, an influence directed towards S causes a deviation BV from that, and the body will therefore end up in C. Without an influence it would in the next period continue in the direction BC with constant speed and end up in d. Instead, an influence directed towards S in C causes a deviation and the body will move to D, et cetera. If smaller periods of time are considered, the polygon ABCD... approaches more and more a curved trajectory and the series of discrete influences becomes a continues influence.

The computer model can finally be introduced as something that performs such a graphical construction very fast, much faster than we could ever do it by hand. Before students could be expected to work with such a computer model two preliminary topics need to have been addressed: (1) how from a given influence in a given situation the motion can be graphically constructed (both in a Newtonian and in a Keplerian way), and (2) how from attributes of the situation the influence in that situation can be determined, i.e. the notion of an influence *law*.

This was the general idea behind the second main theme in the first design. I will now describe the main points of this part of the design, which consisted of five 50-minute lessons (lesson 3 through 7).

The second main theme starts with the point that the explanatory scheme for motion can also be recognised in Kepler and Newton, two important figures who were interested in explaining the motion of heavenly bodies. Next a graphical explanation is given of how influences can be identified (in magnitude and direction) in a given motion or how the motion can be constructed when given the influences. This includes the relation between influence and motion expressed in my translation of Newton's second law in terms that can also be used for Kepler's equivalent second law: deviation (from the influence free motion) = influence/laziness[2]. The term laziness is a translation of 'inertia' and is a measure for how strongly an object reacts to an influence. The larger the laziness, the smaller the reaction (in the form of a deviation from the influence free motion) to some given influence will be. The reason for using a word like 'laziness' instead of 'mass' is the same as for using 'influence' instead of 'force', namely that in this way it is less likely that students will directly associate all kinds of unintended meanings to the word.

The following excerpt from the students' booklet shows how the graphical explanation is given. It is meant to illustrate how such a graphical construction visualises the explanatory scheme and also to give an impression of the complexity of the topic.

1.8 The relation between deviation and influence

A general expression of the relation between motion and influence, which applies to both Kepler and Newton is: A deviation from the influence free motion of an object equals, in magnitude and direction, the influence by both person and environment affecting that object, divided by the laziness of the object. Put in a scheme:

$$\text{Deviation from influence free motion} = \frac{\text{Influence}}{\text{Laziness object}}$$

Since a deviation has got a magnitude and a direction, an influence has those too. The deviation from the influence free motion can be indicated with an arrow, which points from where the object would have arrived without influence to where the object arrived with influence. The length of the arrow indicates the magnitude of the deviation and its direction indicates the direction of the deviation. We can indicate the influence with an arrow as well. This arrow has to point in the same direction, because the influence has

[2] In the Newtonian case the deviation from the influence free motion is a deviation from motion with constant velocity and therefore an acceleration (therefore $a=F_{Newton}/m$). In the Keplerian case the deviation from the influence free motion is deviation from rest and therefore a velocity (therefore $v=F_{Kepler}/m$).

got the same direction as the deviation. The length of the arrow that designates the influence indicates the magnitude of the influence, but this length does not have to equal the length of the arrow indicating the deviation. That depends on the size of the laziness. When the laziness of some object is for instance three (we still have to decide upon a measure for laziness), then the size of the influence will be three times the size of the deviation. We then draw the influence arrow three times as large as the deviation arrow.

We can now try to indicate for a known motion what the influence must have been according to Kepler and Newton. Vice versa we can also indicate from a known influence what the motion would look like, according to Kepler and Newton.

1.8.1 From motion to influence

According to Kepler:

Assume that an object with laziness 2 is at some time in A and that it is given that some time later it is in B (Figure 7).

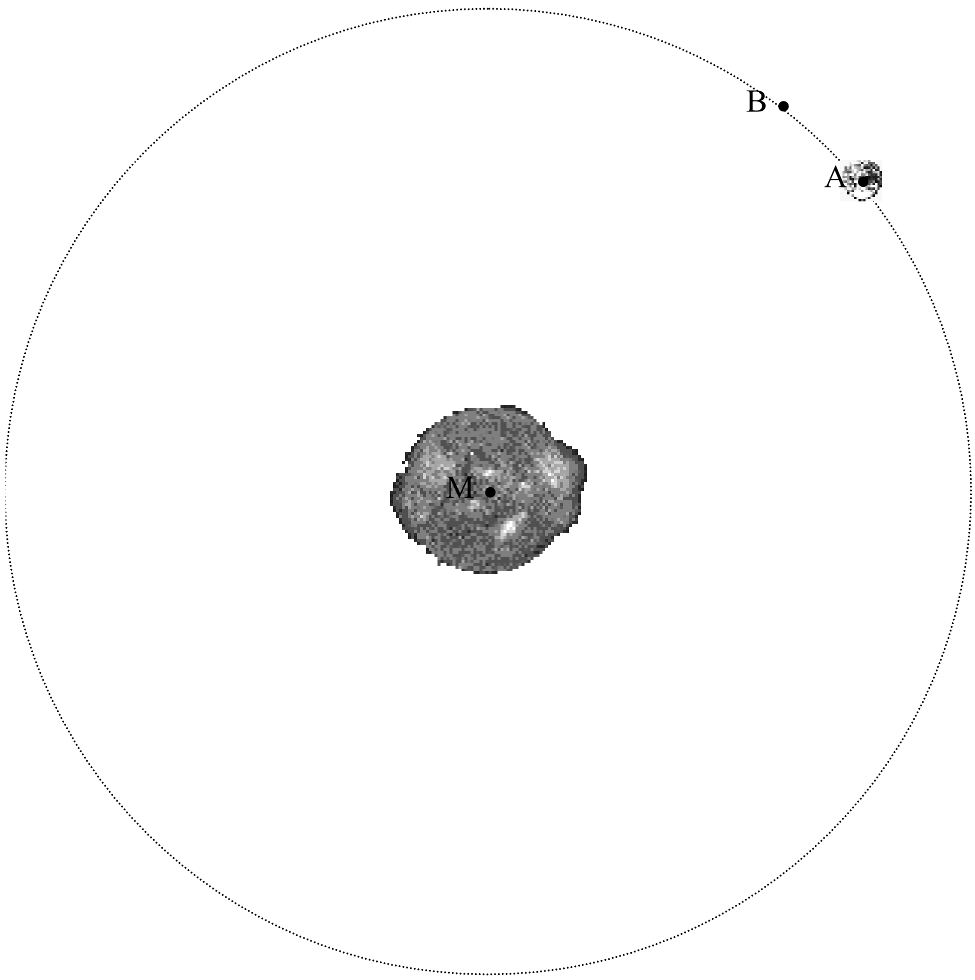

Figure 7: From A to B

Can we now determine what the influence during that time must have been, according to Kepler? We can with the help of the formula ‘deviation = influence / laziness’. We can determine the deviation from the influence free motion in the following way: When no influence had operated, the object would have remained in A according to Kepler, for rest is the influence free motion according to Kepler. However, the object arrives at B. The deviation from the influence free motion can therefore be depicted with the arrow from A to B (see Figure 8).

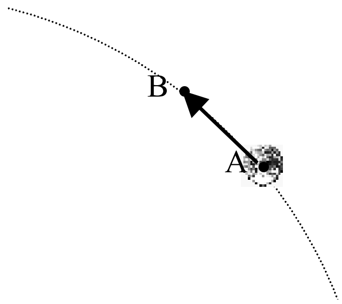

Figure 8: Deviation

We can now determine the influence with the formula 'deviation = influence / laziness'. Since the object has got laziness 2, the influence is two times as large as the deviation, but in the same direction. In Figure 9 this influence is drawn in the form of a thick arrow.

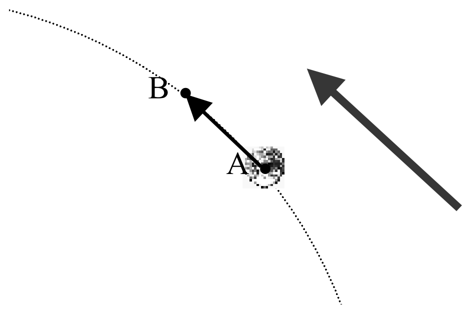

Figure 9: Influence

Similar explanations were given for Newton and for the reversed case where from given influences the motion was constructed. Note that the first design started with determining the influence from the motion.

To develop some confidence in the main point of how the graphical method is an expression of the explanatory scheme for motion and that motion can be determined given an influence and vice versa, students were then meant to practice with such constructions. To illustrate the type of assignments that were offered I present the first one below:

Assignment 8.

An object is moving from A to B during some short time and has got a laziness of 3. See the figure below.

a. Assume that when there was no influence, the object would arrive in B’ after the mentioned short time. Indicate the Newtonian influence with a (red) arrow to the right of the figure.

b. Where would the object have arrived after the same short time and the same influence when its laziness would have been 2 times as large?

c. Where would the object have arrived after the same short time and the same laziness (of 3) when the influence would have been 2 times as large and in the same direction?

Since the details of this graphical method are quite complex and students might therefore easily lose sight of the main point, the explanation of and guidance by the teacher should emphasise that the main point here is that influence can be determined in principle from motion and vice versa and that the way this is done directly expresses the explanatory scheme (in a graphical way). Apart from emphasising the main point when students are working on the various assignments, coached by the teacher, the teacher also expresses this at transitions from one set of activities to the next. For instance from applying the graphical method to the next set of activities about the role of the length of the time interval, described below.

The length of the time interval between successive positions is an important variable. To show that diminishing the time intervals in this constructions leads to more fluent trajectories and better calculations[3], students were presented with a computer simulation showing a quick succession of constructed positions of a thrown object, first with a large time interval and then with a smaller time interval.

The idea of an influence law (force law) as a way of expressing the magnitude of an influence as a function of attributes of the configuration in which the motion takes place is introduced by first recalling the already encountered notions of Kepler and Newton concerning relevant attributes of the configuration like the distance between heavenly bodies and suggesting how this can be expressed in a formula. A couple of questions guide students to the notion that many formulas can be plausible in the sense that they all express the same qualitative regularity like ‘the larger the distance, the smaller the

[3] The precise role the time interval plays is too difficult to address in depth.

influence'. Useful alternatives that later will be put to the test in a computer model are the Keplerian influence laws $I_K = R/r^p$ (in which I_K is the Keplerian influence from the sun dragging the earth, R and r are the attributes of the configuration with R the rotation speed of the sun, r the distance between sun and earth and p = 1, 2 or 3) and the Newtonian influence laws $I_N = H_{sun} \cdot H_{earth}/r^p$ (in which I_N is the Newtonian influence from the sun attracting the earth, H_{sun} and H_{earth} are the heaviness of the sun and the earth respectively and here also p = 1, 2 or 3). 'Heaviness' is a measure for the strength of the attractive influence of the sun on the earth (in this case). These influence laws may seem plausible, because they are in agreement with intuitive notions that the influence should decrease with the distance and increase with the rotation speed in the Keplerian cases (remember that according to Kepler planets were dragged along as a consequence of the sun's rotation) or with heaviness in the Newtonian cases. Students were also asked to come up with some additional factors they think the influence might depend on.

It remains to be seen, however, whether these particular plausible influence laws (and many others may seem equally plausible) are also empirically adequate. An influence law is empirically adequate when the modelled motion of an object moving under the influence described by that law matches the observed motion of that object. Using a computer model that visualises both an 'observed' motion and the modelled motion of a planet moving around the sun, this notion of matching can easily be made clear to students. The computer modelling environment (Modellus) can be introduced as a way of quickly calculating the resulting motion of particular assumptions for an influence law. Students can investigate Keplerian and Newtonian models with Modellus. They solve the 'matching problem ', i.e. they try to find influence laws that result in a match between the motion of the modelled planet and the 'real' observed planet. For this they were presented with a Newtonian and a Keplerian model of earth and mars moving around the sun, see Figure 10 for the computer model interface.

This model shows the sun and four objects moving around it. Two are the modelled earth and modelled mars. The motion of these is controlled by the parameters of the model, that the students can alter. Two follow the 'observed' or real motion of earth and mars and can not be altered. In this model students can alter the influence law by adjusting the power of the distance r in the Newtonian formula $I = H_{sun} \cdot H_{planet}/r^p$ (with p=1, 2 or 3) and in the Keplerian equivalent $I = R_{sun}/r^p$, with R the rotation speed of the sun around its axis, and they can also alter the heaviness and laziness (independently) of the sun and both planets. More details of the precise setup of this and other Modellus models will be presented in chapter 5. I expected this model to show in an intuitive way when a model can be judged empirically adequate, namely when a choice for a particular set of parameters affects a match, that is: the modelled planet stays on top of the observed planet. Students were asked with some hints to describe how they can see that the presented model is a Newtonian (respectively Keplerian) model, to try and affect a match between the model earth and the observed earth for three influence laws (p=1, 2 or 3) and to judge the value of the model by trying to match the second planet as well. For the Newtonian models a match turns out to be only possible for p=2 and when heaviness equals laziness. In that case the match is perfect. A similar investigation of Keplerian models does not result in perfect matches, though there are near perfect cases.

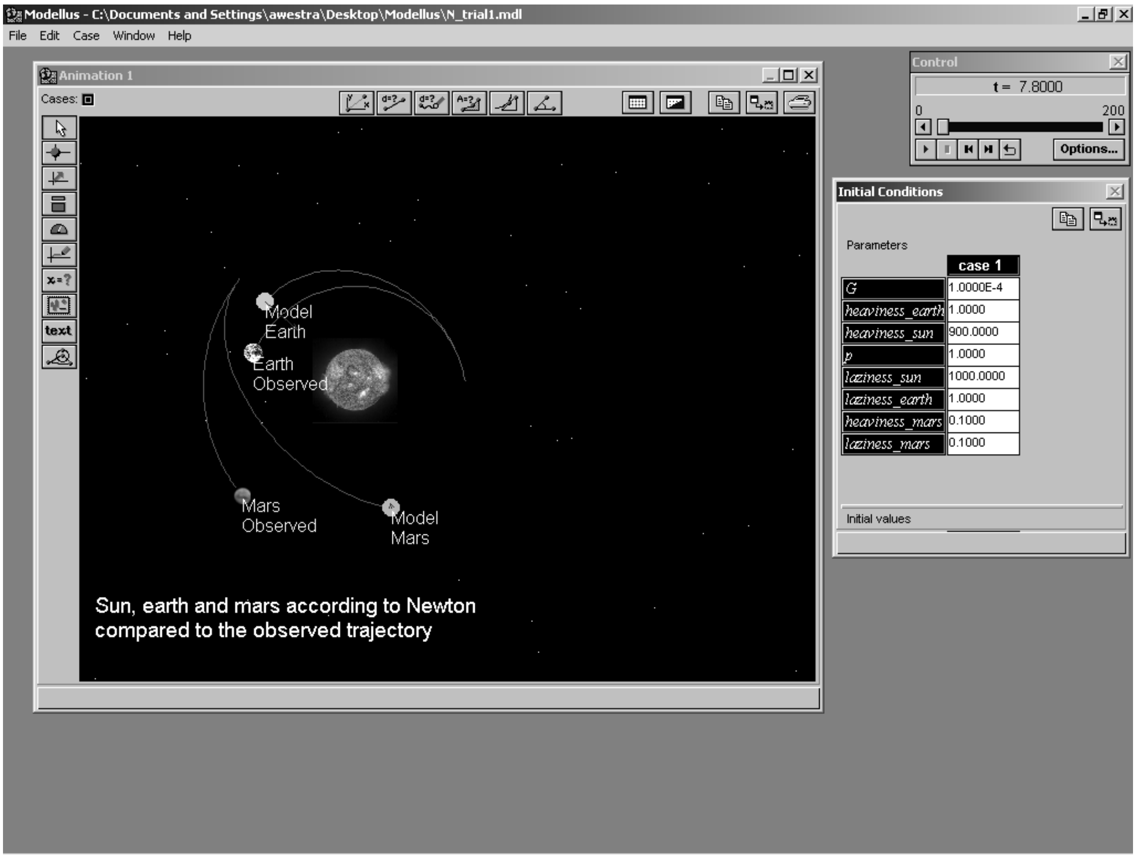

Figure 10: Interface of the computer model of two planets moving around the sun

The teacher's role during the modelling assignments was to keep students on track (and keep the momentum), answering questions, suggesting strategies, applying short corrections et cetera (normal coaching/guiding stuff). When most students were ready he would then evaluate these assignments in a class discussion in which the main point (of how the graphical method is an expression of the explanatory scheme for motion and that motion can be determined given an influence and vice versa) would become clear as much as possible in close relation to student input.

2.2.2. Results leading to revision of the first design

In this section I will describe some results from the first trial and organise those around four subsequent topics addressed in this second main theme: the transition from the first main theme to the topic of heavenly bodies, the method or technique of graphical constructions, the notion of influence law and constructing empirically adequate models by means of computer modelling (the matching problem).

Transition to motion of heavenly bodies

As was said in section 2.1.2 the explanatory scheme was not made explicit effectively. In the transition to the motion of heavenly bodies as explained by Kepler and Newton after the common motions seen in the video fragments in the first main theme, the teacher did not address the intended bridging notion that Kepler and Newton also used the explanatory scheme in their explanations of motion of heavenly bodies[4]. Students could therefore not be expected to see the investigation of the ideas of Kepler and Newton as specifications of the explanatory scheme. This and some other deviations from the plan can be related to the way the teacher was prepared and will be further discussed in section 3.

Graphical construction

Students paid a lot of attention to the explanation of the teacher of the graphical method of constructing influences from a given motion and also to the assignments exercising this method. The assignments were on average completed not too badly, but this took quite some help from the teacher and use of some available sheets with worked out solutions to these problems. The teacher, moreover, focussed on the details of the construction instead of emphasising the main point, that motion can *in principle* be determined given the influence law and vice versa. It was not expected, after all, that students would be able to completely grasp all technicalities of these constructions.

The assignments were to a slight extent evaluated in class, from which became apparent that most students at that time had neither got the main point nor understood the construction technique. To illustrate this the following fragment shows a part of the evaluation in which one student (Els) correctly completes a graphical construction on the blackboard, but the rest of the class is left in the dark.

1. T: You do not get it completely. (4s) Who wants to help? Who can draw Kepler, who can draw Newton? [Els is moving forward]. Fantastic Els.

[Els draws both situations correctly, without any comments.]

2. T: We are talking about the same motion. (3s) Does anyone have a question on this?

[laughter, in the sense of 'yes, of course']

3. T: Yes, Wilco.
4. W: Yes, I do not get at all how she arrived at that, really.
5. T: Can you clarify, Els, how you arrived at that?
6. E: With Kepler [one] must the, because it is 1/2 , do times two. It then becomes two times as big, that arrow. That is how far it goes and then it just goes in that direction, in which the arrow is going. You just put them one behind the other and that is where it ends up.

[The teacher writes the formula deviation=influence/laziness on the blackboard]

7. T: Yes, when the influence is known, and the laziness is 1/2, dividing by 1/2 is the same as multiplying with 2, then the deviation is an arrow that is two times as large as the influence. Hence influence 1 with Kepler leads to a motion from point A, a deviation from point A to point B and influence 2 from B to C.

[The teacher writes points B and C on the blackboard.]

8. T: Is that logical?
9. S: That means that they are equal.
10. T: What is equal, Sebastiaan?

[4] Of course this notion could be expected to be harder to get across, given the ineffectiveness of its introduction in main theme 1, but attention to this point at this stage might have served a purpose in repairing the earlier failure in the sense of that the explanatory scheme may have become somewhat clearer in retrospect.

11. S: Influence 1 and 2.
12. T: That is as such not the point of the question, but that might possibly be equal. It does not matter as such.
13. T: That concludes Kepler. Newton is somewhat more difficult. Sebastiaan can you explain Newton?

That students had difficulties with the construction technique is illustrated by that many students have no clue what Els was doing, indicated by the laughter after (2), which sentiment was expressed by Wilco (4). Someone already familiar with how these constructions work can understand Els' explanation, but of course not the students that have problems understanding this method (6). The addition of the teacher to Els' explanation (7) does not help for the same reason.

Later on in the course students did two assignments that called for an application of the graphical method. They were generally unable to do this, which indicated that the impression that students did not understand this method had been correct.

The main point did also not come across. The teacher hints at the assignment having some point in (12), but does not explain what it is. Students are probably left with the impression that the technique of solving this kind of problems is somehow important. Another indication that the main point had been missed was the reaction to an animation of a quick construction of a succession of positions of a thrown object. For many students only at that stage the notion dawned that constructing subsequent positions actually amounts to constructing a motion. This was an unintentional but fortunate effect of this demonstration, which was originally meant only to illustrate the influence of the size of the time interval. If this insight would have dawned sooner to students, they would not have shown signs that the penny had dropped here.

<u>Discussion of these results concerning the graphical construction</u>

In retrospect the extra light the animation had shed can be understood since all examples and assignments involved only two or three subsequent positions (in which the technique of constructing demanded all of the attention), that were mostly abstract points A and B et cetera (see also the example of an assignment in section 2.2.1). The notion that something is actually moving can be quite easily overlooked.

Working with the graphical construction method was not seen to lead to more insight in the explanatory scheme of which it is a visualisation. One factor that has inhibited such insight is that the graphical construction began with determining influence from motion (cf. section 1.8.1. of the student booklet, presented in section 2.2.1). This, however, is somewhat counter intuitive. One can of course normally argue from result to cause, but this does in general seem to make an argument more difficult when it is not made explicit that the argument uses such a reversal. A fragment that illustrates the difficulty of this counter intuitive approach is the following:

1. T: You also don't get it. What do you not get?
2. Els: Well look, they say, they talk all the time about it is going in this direction, then it is going in that direction. I think that is nice to know, but I do not get why it is going in that direction.

Another inhibiting factor is the introduction of laziness by means of the rule deviation = influence/laziness. The difficulty of getting a clear picture of what is meant by deviation and influence was underestimated. Introducing laziness in terms of its relation to deviation and influence, that were still unclear at that time, led to problems. The following example is quite typical for the confusion surrounding laziness:

1. B: Oh yes, I get that now, but what is laziness?
2. T: What is laziness. Can you imagine something what that could be?
3. B: Yes, that it stops for a moment or something.
4. T: That it stops for a moment. (4s) Someone who is two times as lazy...
5. Emma: When you are lazy, you go slower.

The functioning of the explanatory scheme in constructions is not recognised. The notions of influence free motion, influence, deviation and laziness are still so unclear that they can hardly help in clarifying the construction technique. Or, vice versa, the technique can hardly be expected to illustrate the explanatory scheme. At the most the relation between explanatory scheme and graphical constructions as a visualisation of the scheme might be seen in retrospect.

Notion of interaction law

There are two aspects of the notion of an interaction law that are relevant here. Firstly, knowing what an interaction law is, namely a formula that relates the influence (here on heavenly bodies) to attributes of the configuration[5] (of these heavenly bodies). Secondly, being able to come up with concrete assumptions for influence laws and being able to express assumptions for influence laws, if not one's own then at least Newton's and Kepler's, into mathematical formulas.

Related to the first aspect I cannot say more than that the example discussed in class was confusing and did not show the relation of influence and attributes of the configuration:

1. T: You don't get it completely. You mean that you cannot think of something where it [the influence] might depend on? Or have you not yet thought about it?
2. C: Yes, I have, but …
3. T: You find it very difficult. Nicky, can you think of something?
4. N: Yes, gravity and attraction force.
5. T: The gravity and attraction force.
6. S: That is the same, isn't it?
7. T: Yes, they are both forces, if that's what you mean. That is a possibility: gravity and attraction force. How could it [the influence] depend on these, Nicky?
8. N: …
9. T: In assignment 14 is asked: When the gravity or attraction force is larger, the influence is then larger or smaller, you think, Nicky?
10. N: Well, with the gravity it is larger.

[5] 'Attributes of the configuration' is a monstrous label for things that can also be called 'influence affecting factors'. Both phrases are painful to the ears, but I cannot think of a better way of putting it.

11. T: With the gravity it is larger, then the influence is larger when the gravity is larger. And with attraction force this is different?
12. N: Yes, I think so.
13. T: When the attraction force is larger, the influence will be?
14. N: Smaller.
15. T: Smaller, you think.
16. T: Eh, so in assignment 13 we first try to think of something it [the influence] may depend on. Where does it depend on? In assignment 14 we try to see how it could depend on it and in assignment [15?] we will see what the consequences are for the formula. When the influence is indicated with an 'I' and when gravity is increasing the influence is increasing, how would that formula look like, Nicky?
17. N: I haven't got that one.

According to Nicky the influence depends on gravity and attracting force (4). Maybe because the teacher is not sure about what Nicky means with these terms, he continues his line of questioning by asking how the influence depends on these two 'factors' (7). Here Nicky does seem to attribute different properties to the mentioned factors, gravity increasing the influence when it increases (10) and attraction force decreasing it (12, 14). She was not reading her answer aloud. I had the impression that she was merely talking along with the teacher, inventing things to say on the spot. She could not think of a formula (17).

Related to the second aspect: students were unable to come up with possible attributes by themselves. Furthermore, the distinction between influences and attributes, or influence affecting factors, was found to be difficult, as is illustrated in the following fragment of a couple of students who had just identified pedalling, gravity, speed and wind as influences on a bicycle rider. This fragment came from later in the course:

1. Iwan: Now it says here: on which things does the influence depend?
2. Tara: All, I think.
3. T: Think of an influence law for each influence. Then you should first think of eh (8s) on which things does it depend. How does that influence depends on...
4. Iwan: On all those [meaning the mentioned influences of pedalling, gravity and wind] doesn't it.

[...]

5. T: Try to think what these influences might depend on. And try to arrive at an influence law.
6. Tara: [at the same time] ...(it depends on the) gravity
7. Iwan: It depends on the speed. And other eh 'brakings' ... on the surface, frictions.
8. T: Gravity you mentioned, where could gravity depend on?
9. Iwan: Well....eh...the force of attraction.
10. T: For example.
11. Emma: I though force of attraction and gravity were the same.
12. T: Yes. That is actually kind of the same.
13. Iwan: Yes, but what is it? I don't get ...
14. T: How could a gravity become larger?
15. Iwan: When the object is larger.
16. T: For example, yes, yes.
17. Iwan: Ok, so we can write down that gravity is larger...
18. T: Ok so it could depend on the size of the object, yes.

19. Iwan: 'On which things does the influence depend?' Ok, size of the object.

The question which things the influence depends on (1) is first answered by Tara and Iwan as 'all' (2, 4), that is all the identified influences like pedalling and gravity. The teacher focuses the attention to one influence: gravity (8). Iwan says gravity depends on the force of attraction, but is uncertain (9), which is approved by the teacher (10), leading to a confusion of Emma (11). The teacher then agrees with Emma (12), confusing Iwan (13). This is finally settled by finding a proper influence affecting factor, namely 'size of the object' (15, 17, 18 , 19).

Students were able to find alternative formulas that correctly captured the qualitative notions of Kepler and Newton concerning influence laws. They merely needed the help of some examples of how such a formula might look like. The conceptual difficulty seemed to lie mainly in the value of a formula they invented themselves. Although they were able to do it, students found the translation of assumptions for the relation between influence and influence affecting factors into a formula a strange thing to do. When students were able to formulate some assumptions for the relation between factors affecting influence and influence itself, they were also able to translate this assumption in a mathematical formula. When the formula was missing in their written answers to the relevant questions, the assumption for the mentioned relation was missing as well. Apparently the translation into a mathematical formula as such is not the problem. The strangeness seemed to lay mainly in the fact that one was allowed to 'invent' a formula in this way. This is in contrast with the absolute way in which formulas are commonly treated in science classes, as simply given instead of conjectural.

Discussion

Reflecting on the confusion between factors affecting influence and influence itself, this seems to be a category mistake. The influence that can be related to motion with the rule deviation=influence/laziness is in effect the *total* influence, which is the sum of all particular influences. Each kind of these particular influences depends on specific factors that also determine the kind of influence. So can the total influence I be thought to consist of particular influences like gravity G, friction F, muscle force M, et cetera so that $I=G+F+M+\dots$. For each of the particular influences some regularity relating influence affecting factors to influence can be identified and sometimes expressed in an influence law, like $G=H_1 \cdot H_2/r^2$ or $F=C \cdot v^2$. What characterises a particular kind of influence as being of that kind is precisely the type of influence affecting factors that are identified[6]. The design may be improved by more clearly distinguishing between factors affecting influence and influence itself.

Another explanation for the confusion between influence and influence affecting factors lies in the fact that the use of constructing interaction laws can only be seen when one also sees a way of testing them, which the students at this stage could not. Without this

[6] For example some influence on an object that is seen to vary according to its distance to a magnet and the kind of material it is made of (for example attraction when iron, no attraction when plastic) may trigger the introduction of a whole new kind of influence, since the identified influence affecting factors (distance and material) do not fit in with the already used categories of G, F and M.

notion it may be difficult to see the point of expressing some unknown influence in *equally unknown* factors like heaviness or rotation speed. After finding that a match can be effected with some particular influence law with specific values for heaviness or rotation speed the use of an influence law (and therefore also the distinction between influence and factor) can be better appreciated.

Computer modelling

Students mainly used trial and error strategies when trying to solve the matching problem. This I observed to be the case with most students. It can be illustrated by one student, Tom, who described his way of working in the next example:

1. Tom: You have to get them both in one trajectory, don't you?
2. I: Yes.
3. Tom: I am just trying to change something and see how it works.
4. I: Ok. What precisely are you changing?
5. Tom: That 'p' and the laziness.
6. I: Ok, yes.
7. Tom: I can perhaps also do heaviness, but I don't know.
8. I: Hm hm

The meaning of the parameters in the models was not immediately clear, but could become clearer with some help. The following two examples illustrate how some guiding questions quite easily led students to correct use of the parameters in both Keplerian and Newtonian models. The first example concerns some (resolved) uncertainty about R in a Keplerian model:

1. Els: Sir, it is going way too fast compared to the observed...
2. I: Yes.
3. Els: ...but how can you change that once again? Because we do not know that.
4. I: Eh, your model is going too fast?
5. Els: Yes.
6. I: Ok, where does it all depend on?
7. Els: Ehm, the influence.
8. I: Ok, so that influence, does it have to become larger or smaller?
9. Eve: Smaller.
10. I: Has to, become smaller. How can you make the influence smaller with Kepler?

[...]

11. Els: When that were three, it would move too fast, but we cannot change that, so we have to change the rotation speed, but I don't know in which direction. Whether it has to get larger or smaller.
12. I: Well, what would you think? Think about the spokes modes.
13. Eve: When it goes too fast it has to get smaller.
14. I: Yes. Yes exactly. Well, you do that.

These students realised that the influence should be made smaller, but were uncertain as to how to do that. The next example illustrates the same phenomenon, only now with the parameter heaviness in a Newtonian model:

1. I: Well ok, what is happening now?

2. S1: The influence is too strong.
3. L: Yes, I was about to say that.
4. I: The influence is too strong. Ok. You would like to decrease it then. Well, how can you do that?
5. L: Eh
6. I: On what does that influence depend?
7. L: The heaviness?
8. I: Yes, but why do you say that so questioningly? The heaviness.
9. L: [giggle] yes, I know ...
10. I: Yes, but of course the heaviness. You can even see it here. The influence depends on the heaviness of the sun, which is not between these, we cannot change that one, but the heaviness of the earth also. You can change that one.

The assignments were expected to fulfil the role that the guiding questions here do: to relate the function of the parameters to motion via their role in the influence law. Without such help students were seen to abandon the assignment in frustration after some time. The modelling assignments by themselves did therefore not serve their purpose of deepening the insight in the functioning of and relations between the variables in these models.

The purpose of the matching problem was instantly clear: finding such values for the parameters that the modelled motion equals the observed motion.

The difference between Keplerian and Newtonian models did not become clearer. Students mentioned the choice for influence free motion as a difference, which of course it is, but I think this was more the result of light drill than on insight in the functioning of the explanatory scheme. At the end of the course some students still could recall the assumptions for influence free motion, but could not explain why these were important.

Another guiding function in the testing of models in the matching assignments could be the use of the criteria of empirical adequacy, plausibility and broad applicability. Information about whether students used these criteria can be found in the relevant sections of the essays students wrote later in the course and that will be described in section 2.3.1. I therefore selected all the fragments from these essays that were related to the testing of models and types of models. I could not find any recognisable use of criteria in 6 of the total of 22 returned essays. The fragments were selected by looking for those instances that students wrote something about the comparison of models in general or (in most cases) Keplerian and Newtonian models in particular.

From all these fragments those that implicitly use the criterion of empirical adequacy are presented below. Two other researchers, one with detailed knowledge of the entire introductory course and one who had only been explained the meaning of the two criteria of empirical adequacy and broad applicability, were asked to indicate in these fragments instances of implicit use of these two criteria. The agreement between the three of us was large. Here follow the fragments containing these criteria:

> Joffrey: We saw in this course that Newton was more precise than Kepler. Most of the time in the Modellus the ideas of Newton were closer to reality than were the ideas of Kepler. The strong point in the model of Kepler was that the properties were easier and

> easier to change and to understand. The weak point in the model of Kepler was that it is not very precise. When you change something in this model, it has much more impact. With Newton the model is incredibly precise. This could almost be made equal to reality.

The phrase ‘easier to understand’ implicitly indicates the criterion of plausibility.

> Sophie: When can we say that we have completely understood a motion, or can completely explain it? I think the answer to this question has to be: when your predictions according to a model agree with your observations. We have ‘tested’ this on the computer. You had to match the observed earth, by adjusting the model of the modelled earth, to the modelled earth.

> Michael: With Modellus (planets) and with an experiment (section 1.13 - measuring an influence), turned out that the model of Newton was better applicable than the model of Kepler. The book stated that the model of Newton was better applicable on situations on earth than the model of Kepler.

‘Better applicable’ in the sense of resulting in a better match, therefore the criterion of empirical adequacy is implicitly used.

> Bertine: Newton was right much more often. The model of Newton fits better than that of Kepler.

‘Fits better’ indicates empirical adequacy. ‘much more often’ indicates broad applicability.

> Emma D.: I consider the model of Newton to be quite useful and I like that I know more about it now, but that of Kepler I consider much less useful, and according to me it isn’t right. In the computer lessons with the program Modellus it also turned out that one could better adapt the model of Newton to make it synchronise the real world (bungee jumper) and let the planets take their right trajectories.

> Rachel: On the computer we could see that both models resemble the reality fairly well, and with a few adjustments we could match the models to the real trajectory of the earth. [...] The most important example in this course had been the model of Newton, which is the one we mainly used with the computer models, probably because it agrees best with reality.

> Mark: I find the model of Kepler (which we used with Modellus) best. It is a model that is not too complicated and it can be easily filled in in such a way that it agrees with reality. With Newton I find that more difficult. [...] it turns out that you have to choose which model is most convenient in each situation.

> Mathilde: I found the model of Newton easier and more logical than Kepler, because I found Kepler more difficult to understand, also because Kepler was more often wrong. Also [on] the computer (with the program Modellus) Newton was more often right than Kepler.

Mathilde also uses implicitly the criterion of plausibility when she indicates that the Kepler model is ‘more difficult to understand’.

> Els: Furthermore I have learned [...] that the model of Newton agreed best. [...] I have learned how to adapt the [computer] model to reality.

> Koen: [...] On these computers we could enter their [meaning Kepler's and Newton's] laws, and subsequently quickly see whether their statements were right.

Koen's use of empirical adequacy in this example is very implicit, as is also the case in the next one:

> Abe: The way [to predict a motion] of Kepler is more difficult or not at all applicable to a motion on earth. The Newtonian way is always well applicable. That was the case in every assignment I did.

'Difficult or not all applicable to a motion on earth' means impossible to find a match, therefore very implicit use of empirical adequacy.

> Tara: In some situations the Keplerian model is better applicable than the Newtonian model, but in other situations that is the other way around. [...] After a couple of weeks participating in this course I knew that the Newtonian model was better applicable on situations on the earth than the Keplerian model. Later we found out that the Newtonian model still contained errors, and that a small piece was missing.

> Tom: After a few weeks we found out that the Keplerian model was less applicable to situations on earth than the Newtonian model. But after that it turned out that also the Newtonian model exhibited some hick-ups, as if something was missing.

> Iwan: You can only say that you understand motion when you have determined in practice that your theoretical predictions are right.

As can be seen from these fragments quite some students (13 from the total of 22 returned essays) implicitly use the criterion of empirical adequacy, albeit sometimes *very* implicitly. Also the criterion of plausibility was on a few occasions encountered. Apparently these criteria can serve in guiding the testing of models.

Discussion

That students use trial and error strategies is not surprising since a more insightful matching procedure requires knowledge of the workings of the parameters in the model. Without knowing what for instance laziness is, changing the value of the parameter laziness in a computer model can at the most lead to some observations of changes in the motion, but will not lead to understanding why the motion changed as it did. In order to make students realise the function or meaning of parameters or adopt a different strategy some guiding questions proved necessary and sufficient. The assignment on its own did not provide sufficient guidance and probably made students adopt a trial and error strategy. The lack of guidance in the assignment was due to its 'density' of questioning. A whole range of questions was condensed into one final question, which was the only one that was actually put to students, namely to investigate which models were empirically adequate. This involved a range of activities like focusing on one planet to start with, noticing its motion, determining how this motion should change, determining how to change it (in what way, with which parameters) and repeating the process for other influence laws. Students would have benefited from more guiding questions in between in the material. Apart from that students were seen to implicitly use the criterion of empirical adequacy in their matching activities, which is therefore as intuitive as was expected and can be retained in the second design.

2.2.3. Second design

The main conclusion from the results presented in section 2.2.2 is that students had insufficient perspective on what they were doing. This was partly caused by the fact that the first main theme had some shortcomings that are still felt here. Furthermore the second main theme contained unnecessarily troublesome elements like the counter intuitive start of the graphical construction section in which force was determined from a given motion, the introduction of laziness with the rule deviation=influence/laziness or the density and difficulty of the computer modelling assignment. However, even when these troublesome elements had been improved, students would probably still have lacked sufficient sight on what they are doing. The graphical construction is and will remain difficult. Students will have to keep clinging to the details with the danger of loosing themselves in those details. Another disadvantage of beginning with the graphical construction is that the actual goal this main theme works towards, explaining or predicting motions by constructing empirically adequate models, remains too far away. How can this be improved?

The first design can be metaphorically described as first establishing the building blocks and then stacking them to make a building. In this metaphor the building stands for predicting the motion of a planet (or any motion for that matter). The building blocks stand for all the elements that are needed for this prediction. In the second design this order of topics is completely reversed, so that it starts with the building and addresses the building blocks from the perspective of their functioning in the building.

The main reason for this reordering was to make students understand the purpose of addressing the subsequent building blocks. All building blocks (or topics) can derive their meaning from the matching problem, which can be introduced right at the beginning of this main theme. In the first design such an early introduction was not considered, or dismissed since, clearly, understanding the matching problem seems to require some knowledge of influence laws, modelling, laziness and the precise relation between influence and motion (second law). How can this be otherwise? I will argue that the matching problem can be understood without first introducing these building blocks and therefore in turn serve as guide in directing the subsequent study of precisely these building blocks. I will here give an outline of how this can be done and refer for a detailed description to chapter 5 section 4.2.

The second design starts, after introducing Kepler and Newton and emphasising their use of the explanatory scheme, with a similar but improved (less dense and difficult) matching problem (see section 2.2.1), which was the end of the first design. The matching problem can be made intuitively clear to students by means of an illustrative computer model that is demonstrated by the teacher. The goal can (again) be expected to be easily recognised: somehow the modelled planet's motion must equal the observed planet's. Clues for what things are needed to affect the modelled motion can be found using the explanatory scheme and can therefore be thought of or at least recognised by the students, I expect. These required elements all get their purpose in light of this matching problem and are the subsequent topics of the second main theme:

- Influence laws. The modelled planet's motion is affected by an influence. The kind of influence (Keplerian or Newtonian), where it comes from and therefore which attributes of the configuration it depends on, is closely related to the assumed influence free motion. The distinction between influence and influence affecting factors should be clearly pointed out. To determine the size and direction of this influence (needed for calculations) an influence law can be introduced, which can be seen as a specification of the element 'regularity' in the explanatory scheme. The functioning of the used influence law can immediately be observed in the computer model.
- The concept of laziness. This concept merits a more careful and gradual introduction given the reported difficulties. The need for this element can also be seen from the perspective of the explanatory scheme, where it functions in the relation between influence and motion (or deviation from the influence free motion). Here the effect of laziness on the motion can be investigated in the same computer model.
- The rule deviation = influence/laziness. After some qualitative feeling for the effects of influence and laziness on the motion (i.e. the deviation from the assumed influence free motion), this can be made more precise with this rule. The need for precision is expected to be clear from the context of the computer model. In order to calculate motion from given (precise) influences and given (precise) laziness, the computer model has to have some precise way of relating influence and laziness to motion. This can be understood even when the way such calculations are performed is not.
- Graphical construction. Finally and optionally the graphical explanation for the precise relation between influence and motion, which can even include the topic of the precise role the step size of the time plays in the models can be investigated using similar (but improved, e.g. starting with constructing motion from given forces instead of vice versa) pencil and paper methods as in the first design. The big difference here is that the purpose of such a precise investigation in what basically is the procedure the computer program follows in determining or calculating the motion is expected to be much clearer for students. This optional graphical construction module is not necessary for understanding the main theme, which is that in order to explain or predict a motion the explanatory scheme for motion needs to be specified and how such specifications look like.

Outline of the second main theme in the second design

The described revisions led to the second design with a didactical structure that is depicted in Figure 11.

Mechanics	**Motive**	**Explanation**
	which should lead to the feeling that it is a theoretical challenge to explain motions by means of an as yet unknown specification of this underlying scheme (theoretical orientation)	
Specification of the underlying scheme into two specific schemes (Keplerian and Newtonian) in the context of developing and testing models of the motion of heavenly bodies.		
	resulting in a question concerning the fruitfulness of the specific schemes and models	

Figure 11: Didactical structure of the second main theme in the second design

The function of the second main theme is still the same: extending students' knowledge by detailing the explanatory scheme to arrive at empirically adequate models for explaining motion. In the second design this detailing of the explanatory scheme is explicitly made into a guide for understanding the purpose of the subsequent activities, whereas in the first design students could only in retrospect see a similar thread through the activities of this second main theme.

In the process of 'matching' both Keplerian and Newtonian models to the 'observed' motion and seeing that both kinds of models can be made to do the trick one criterion is used all the time: the criterion of empirical adequacy. This criterion does not suffice to base a choice on between Keplerian and Newtonian models, since all used models (including the Keplerian ones) were prefabricated in such a way as to make empirical adequacy possible. The question what can be said about the value of these *types* of models (Keplerian or Newtonian) was expected to slowly grow during the matching process. This question and its answer can fully blossom in the next main theme of the design, which will be discussed in the next section.

2.3. Evaluation of models and types of model in the light of achieving broader applicability.

In the discussion of the first two main themes was seen that students had lost sight of the main thread and did not understand basic concepts like influence and laziness to the expected extent. The accumulated (lack of) results in the first two themes make it rather meaningless to look into the details of the test results of the third theme. The evaluation of earlier activities and continuation of the main thread designed to take place in the third main theme can no longer be expected to yield much results, since this builds on earlier results that should have been achieved before, but were not.

The second design differs from the first. This difference is not primarily based on test results of the third theme from the first design, but on revisions in the first two main themes on which it builds. Since the first themes are different in the second design, the third has to be different as well. The design of the third theme still performs the same function of evaluating models and types of models in the light of achieving broader applicability, but can do so more directly, as will be shown.

I will first describe, in section 2.3.1, how the first design was expected to implement the functions of the third main theme for two reasons. Firstly, it completes the historical picture of the development from first to second design and is therefore illustrative for the used method. Secondly, although the results from the first trial of this main theme, reported in section 2.3.2 were minor, still some noteworthy things may be learned and incorporated in the second design. Section 2.3.3 gives a broad description of the second design.

2.3.1. First design

The second main theme should have resulted in a question concerning the fruitfulness of the investigated models. Since both Keplerian and Newtonian models for the motion of heavenly bodies are both still in the race (although the Newtonian models have a slight lead), the question which one is to be preferred is expected to come up. In the third main theme this question is answered. Models and types of models are evaluated in the light of two criteria, addressed shortly. The didactical structure of the third main theme in the first design is depicted in Figure 12.

The 'reflection on models' part in this didactical structure aimed to make explicit two criteria for determining the usefulness of a model: (1) Whether the interaction theory is plausible. Where does the influence come from? Are the factors and the way an influence depends on them, as described in an influence law, plausible? For instance, an attraction from the sun on a planet that increases with distance is implausible. (2) Whether the influence can be related to 'muscle force'. Is a larger influence according to some to be determined measure in accordance with larger muscle force? In a sense muscle force is a prototypical influence. The Keplerian notion of influence is not in accordance with this criterion, which is a strong argument against Keplerian theory.

In retrospect the second criterion can be considered to be a special case of the first. When some measure for influence failed to be proportional to muscle force it would be considered implausible. At the time of the first trial these criteria were used separately. Note that at that time I did not explicitly use the criterion of broad applicability.

The plan for this reflection consisted of the following elements: The investigation of a simple motion on earth, introduced as a means to say more about the value of the two types of models. Applying Kepler and Newton to e.g. a bicycle rider riding with constant speed who stops pedalling shows some problems for the Keplerian model. Since the only apparent influence that remains after the pedalling stops is friction, which is directed in the opposite direction of the motion, the Keplerian model would predict an instantaneous reversal of direction of the motion, instead of a (gradual) deceleration. Another way of comparing the two types of models is applying them to a motion without friction, e.g. using a glider on an air track. According to Kepler the forward influence in such a case would have to be greater than zero, whereas according to Newton this influence would equal zero. If we would have some means of measuring influence we might be able to check both predictions. After introduction of the spring scale as an intuitive way of measuring influence this experiment is done. This way of measuring influence I expect to be intuitive, because it can be directly related to muscle force: the larger the muscle force is, the larger number a spring scale indicates. Some measure of influence that would *not* adhere to such a regularity would be considered to be strange indeed. The conclusion of this reflection is that the Newtonian models are to be preferred since both situations, the bicycle rider and the frictionless motion, had led to problems for the Keplerian model. The implicit criterion that is used here is the criterion of broad applicability.

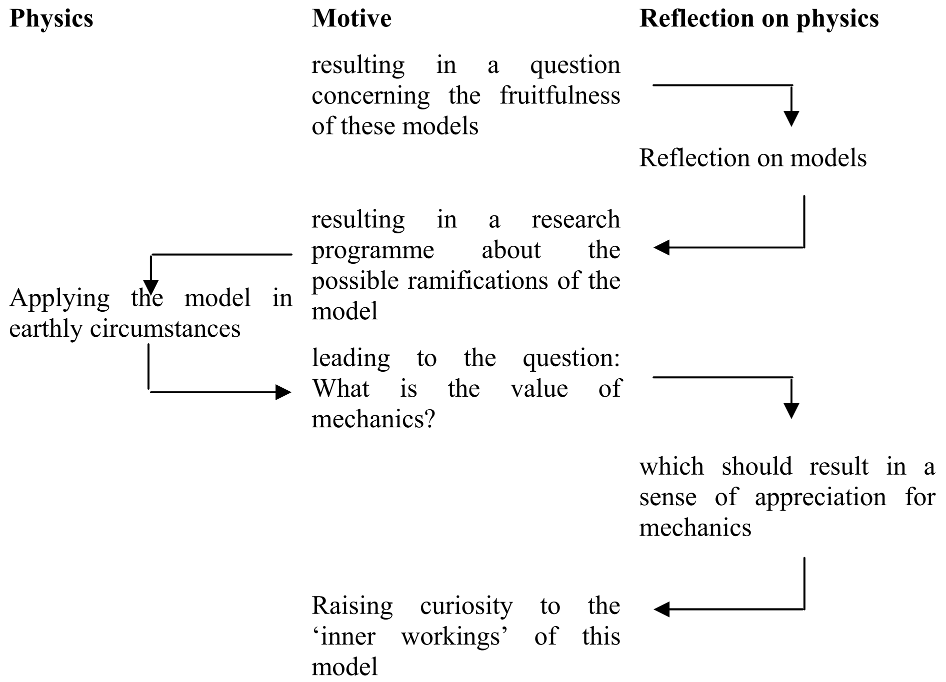

Figure 12: Didactical structure of the third main theme in the first design

The teacher should ensure that the students remain sight on the purpose and meaning of the activities related to this reflection by clearly introducing them as a means for determining the value of Keplerian versus Newtonian models, recalling this perspective from time to time during the details of the investigation of the motions on earth and evaluating them in light of this introduction. In this evaluation the conclusions from these and earlier activities are compiled and made explicit by the following questions in the students booklet. Before the experiences with the first two main themes students were expected to be able to answer those questions as indicated.

- What does the structure of a model for motion look like?

  The expected response was something resembling or describing a figure like the following, which was used in the course.

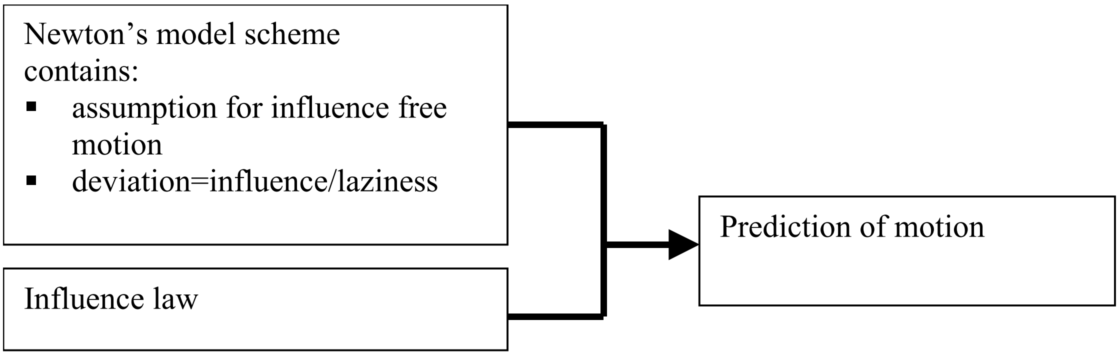

Figure 13: Scheme of the structure of a motion model

- In what ways differ Keplerian models from Newtonian models?

  Here students might give three general differences: their assumption for an influence free motion, the direction of the influence and the particular form of the used influence law (s) and/or say something about their value: Newtonian models are broader applicable, empirically adequate (slightly more so than Keplerian) and allow a plausible (intuitive) measure of influence.

- Why is an influence law needed in a model for motion?

  A precise quantitative description of the influence (at all times) is required in order to calculate or graphically determine the motion.

- How does one arrive at such an influence law? How is a model of motion tested?

  Here students can summarise the process they have been through several times of finding/assuming some relevant factors on which the influence may depend, turn the relationship between influence and these factors in several possible influence laws and check these laws in a model by matching the modelled motion to the observed motion.

- What reasons do you know for rejecting a model for motion?[7]

  The reasons that had been encountered are: a model is not empirically adequate (does not result in a match) or an influence law is implausible (i.e. violates commonsensical notions about the world).

- Which type of models do you prefer: Keplerian or Newtonian? Explain why you think so.

  One argument seen in the second main theme is that a plausible interaction theory can be found in the Newtonian case for heavenly bodies resulting in empirically adequate models. Added to this are the new arguments that in the Newtonian case also a plausible interaction theory can be found for situations on earth, where the plausibility lies in the fact that the interaction theory can be

[7] The reasons for endorsing a model are more difficult to formulate, which may be due to the nature of scientific theorising as described by Popper.

related to muscle force, whereas in the Keplerian case this can not, and that therefore Newtonian models are broader applicable than Keplerian models. The latter argument was expected to be intuitively clear for students and was not addressed explicitly, so that it probably will not be mentioned in response to these questions.

Now the reasons for choosing Newtonian mechanics may be expected to be known, the plan was to further illustrate its power and range by applying it to a more complicated motion. Students can model this motion when they can come up with suitable influence laws. The only influence laws students can be expected to be somewhat familiar with from earlier education are expressions for the force from a spring ($F_s=-C\cdot u$) and gravity ($F_g=m\cdot g$). An example of a (possibly interesting) motion that can be modelled using these two laws and the computer modelling program students are already familiar with is the motion of a bungee jumper. The first step in modelling this motion was to have students realise they would need influence laws and think about how these would look in this case. I expected that presenting them with the situation of a bungee jumper would suffice for some to remember the mentioned influence laws. Others would then probably recognise these laws as appropriate. They would then add the laws to a prefabricated computer model of a bungee jumper, investigate and improve this model, e.g. by adding friction.

Finally the conclusions from these and earlier activities are compiled and made explicit by the following assignment:

Assignment 26:

The conclusion from the preceding activity is that the Newtonian way of doing mechanics is widely applicable. But why would one apply it in the first place? The general motive/goal was to understand change as motion. Did we get any closer to that? Can we at least say that we can tackle motion now? When can we say that we have understood or can completely explain some motion? What is needed to predict a motion? What is the purpose of a model of a motion? What are the weaknesses and strengths of Newtonian models as compared to Keplerian models? What does the structure of any motion model look like?

Write a short essay of about one or two pages in which you describe what you have learned in this course. You could address some (or all) of the above questions. The goal of this assignment is that you look back on all the things you have done and in this way make your own summary and conclusion.

These essays could then be discussed in a way that would provide a bridge to the regular course. The following figure, which is an extension of Figure 13 for the Newtonian case, could serve a purpose to illustrate the point that with the help of the introductory course in principle a broad perspective on dynamics can be retained. Furthermore, kinematics can be shown to serve a technical purpose in explaining/predicting motions, since it plays an important role in calculating motions from force and vice versa.

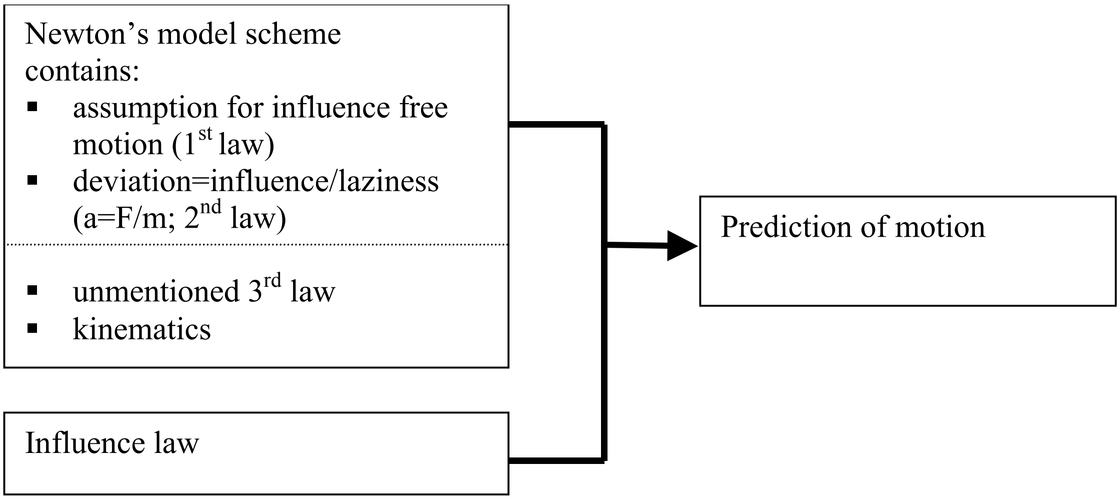

Figure 14: Newtonian model of motion

In this figure some elements of Newton's specification of the explanatory scheme are for the first time labelled in the usual way, i.e. first law and second law. His third law and kinematics are unknown after the introductory course and will be topic of study in the regular course. His scheme together with one or more proper influence laws suffices to predict or explain some particular motion. Kinematics and third law serve a purpose in further understanding the Newtonian scheme. A scheme for which some appreciation should have arisen, as this was one of the goals of the introductory course. The teacher can use this figure in the evaluation of the reflection questions mentioned before. The challenge here lies in using the figure in such a way that students recognise their own answers (as written in the essays) in it.

Apart from the 'relabelling' of laws, also the connection between some other terms used in the introductory course and their more widely used counterparts needs to be addressed. For instance in the regular course the word 'force' will be used for Newtonian influence, mass for 'heaviness' or 'laziness ' et cetera.

This third main theme was expected to take about three 50 minute lessons.

2.3.2. Results leading to revision of the first design

In this section I will describe the main findings from the first trial of the third main theme. Given the fact that the course had already been off-track since the earlier main themes and that also in the third main theme some deviations from the plan occurred (of which some examples will be shown), not very much can be said regarding the results of this main theme. However, notwithstanding these difficulties some findings did surface and are worth mentioning here.

The following two examples give an impression of the kind of deviations in the execution that occurred in this main theme. Firstly, the reflection started with applying Kepler and Newton to a simple motion on earth. No reason for this application was mentioned, unfortunately. Students therefore could not realise that in this way they were supposed to find additional arguments for basing their evaluations of the two types of models on. Secondly, the intended reason for introducing the spring scale was that measuring influence in the second investigated motion, the frictionless one (see section 2.3.1), would provide another example in which the Keplerian model led to problems. This reason was not mentioned. Instead the technical and procedural details of the demonstrated experiment were emphasised, instead of its conclusion.

In this main theme students wrote the essays summarising this course that have already partly been partly presented in section 2.1.2 and 2.2.2. The main interest in this main theme was whether students used the additional criterion of broad applicability when comparing types (Keplerian and Newtonian) of models. In the relevant fragments from these essays[8] I and two other researchers indicated instances of use of this criterion, reaching a large agreement.

There is no use talking about the applicability of an empirically inadequate model. The criterion of empirical adequacy is in that sense more important or more basic than broad applicability. This is reflected in the fragments. The following instances of implicit use of the criterion of broad applicability are in all except one case (Stan) combined with use of the previous criterion.

> Bertine: Newton was right much more often. The model of Newton agrees better than that of Kepler.
>
> Frank: I also understand the differences between the Keplerian model and that of Newton. These two models both perform quite well in predicting the motion of a planet, but only Newton performs well in predicting the motion of the bicycle. [...] I think it would save a lot of time when less time is spent to the motion law [meaning: influence law, ASW] of Kepler. Since that one is not right for all situations it is not really necessary, or at least less important, to discuss. On the other hand, one does learn to test (motion)laws and notice errors.
>
> Lisanne: Because there are multiple theories, we can compare them to each other. That was quite useful, but you do not know which one is correct. We really cannot determine the motion properly. On the other hand I am curious, when it is really researched, what the 'outcome' will be. Perhaps it is possible that the Keplerian as well as the Newtonian way are incorrect. [...] The Newtonian model can also be applied to for example a bicycle, which cannot be done with the Keplerian model. That is one of the strengths of the Newtonian model. I do not know what a weakness of the Newtonian model is.
>
> Stan: Newton was right, for his model also works with a bicycle.
>
> Niek: If I have to compare the model of Newton to that of Kepler and say which one I prefer, I would choose the model of Newton. With Modellus we compared these two models which resulted in that the model of Newton fits better in the Universe. A lesson later we compared these models "on earth" and on an air track. On the air track we found out that a constant motion has in fact a net force of 0. After that we tested both models on a bicycle rider. There too the model of Newton proved best. [...] I myself

[8] This was the same set as used in the discussion of these essays related to main theme 2 in section 2.2.2. There also the way in which these fragments were selected was described.

> consider the model of Newton very well (as far as we have tested), the model of Kepler I am less fond of.

A lot of students did arrive at a correct (albeit implicit) usage of the intended criterion of empirical adequacy and some even of the criterion of broad applicability (and plausibility) even though the shortcomings in the scenario, teacher preparation and execution made this less likely. I find this promising. Apparently these criteria are in fact quite intuitive, as I thought they were, and can therefore be retained in the second trial.

2.3.3. Second design

The second design differs in several respects from the first. These differences were only to a slight extent due to the experiences with the third main theme of the first design. For the most part the differences can be understood as consequences of earlier changes made in the first two main themes. I will first mention the changes and then give an overview of the second design of the third main theme.

Changes

The reflection in this theme can be done more directly. The function of the reflection was to make students realise what still needed to be done, which is finding a way to answer which type of model explains best. For this they have to remember what the goal was (understanding what explaining motion entails) and what has already been achieved (investigating two feasible alternative specifications of the explanatory scheme). In the second design the question which type of model explains best is answered by using a slightly different criterion, namely broad applicability instead of the link to muscle force, because it is more direct. There is no need for introducing measurement and experiment (e.g. with a spring balance). Merely applying Kepler and Newton to situations on earth like the motion of a bicycle rider suffices, since that will already show some difficulties with the Keplerian scheme but not with the Newtonian scheme (see also section 2.3.1). This direct approach will only work if students can value the epistemic virtue of broad applicability, which I expect them to do. This expectation is backed somewhat by the experiences in the first trial, where some students showed quite spontaneous use of this criterion. The notion that a more general theory is better, all other things being equal, than a less general theory is quite intuitive, I think.

The function of the situations on earth to which Keplerian and Newtonian models are applied is different. In the first design they were used to ramify the Newtonian scheme illustrating the power and range of Newtonian models in predicting motions and the process of finding a suitable force law as necessary ingredient for such a prediction. In the second design their function is to demonstrate that applying Keplerian theory leads to problems whereas Newtonian theory does not, thereby showing Newton's broader applicability. In order to fulfil this function, there is no need to model the motion using influence laws and computer modelling tool. The chosen situations on earth can therefore be simpler in the sense that a qualitative description suffices. In the second design the examples of a bicycle rider and hovercraft are used instead of a falling drop and bungee jumper in the first design.

The mechanicism story, adapted from the first design of the first main theme (see section 2.1), is added to the second design of the third theme to give an additional argument for the power and range of (Newtonian) mechanics.

The second design ends with solving the initial asteroid problem introduced at the start of the course in the second version of the design (see section 2.1.3) and a similar bridge to the regular course as was used in the first design. In this way the initial promise (not in so many words, but at least implicitly made) to students that this problem will be solved in the course is fulfilled, which is a nice way of rounding off or making the circle complete. In the second design there is no need to summarise the course in the way of Figure 14, because another figure depicting a summary is used throughout that course, namely Figure 8 from chapter 5. The connection between the terms used in the introductory course and those that will be used in the regular course is depicted in the following table, see Table 3. This table was presented to students in the booklet for easy future reference. It announces to which concepts terms from the introductory course will develop in the regular course.

Introductory course	Regular course
Influence	force
Velocity	velocity
Influence free motion (according to Newton)	rectilinear motion with constant velocity (1^{st} law)
Laziness	inertia
heaviness=laziness=mass	inertial mass=gravitational mass
deviation of influence free motion (according to Newton)	acceleration
deviation=influence/laziness (according to Newton)	$a = F/m$ or $F = m \cdot a$ (2^{nd} law)

Table 3: Terms used in the introductory course and the concepts to which they will develop in the regular course

These changes led to the second design of which I will now give an outline.

Outline of the third main theme in the second design

The didactical structure of the third main theme in the second design is depicted in Figure 15.

Mechanics	**Motive**	**Explanation**
	resulting in a question concerning the fruitfulness of the specific schemes and models	
		Reflection on criteria to determine which schemes and models explain best
	resulting in a plan for further validation of the specified schemes	
Applying the specific Keplerian and Newtonian scheme to other motions		
	leading to a point of closure at which we may ask "which schemes and models explain best?"	
		Evaluation of which schemes and models explain best and which elements of this scheme are still unknown
	resulting in an appreciation of the Newtonian scheme and an outlook on the regular course	

Figure 15: Didactical structure of the third main theme in the second design

As was said before the function is still to evaluate models and types of models in the light of achieving broader applicability. The question concerning the fruitfulness of models and types of models with which the second main theme ends is reflected upon. From this reflection surface the already used criteria of empirical adequacy and plausibility (to select between models) and the now explicitly used criterion of broad applicability to guide a selection between types of models. This results in a plan for further validation of the schemes, namely by applying them to other than planetary motions. This plan is executed by applying both Kepler and Newton to simple motions on earth, e.g. those of a hovercraft and a bicycle rider. This provides additional information about which scheme explains best. Evaluating this information in light of the criterion of broad applicability should result in an appreciation of the Newtonian scheme. The evaluation also makes acceptable the study of some details in the Newtonian specification of the scheme that are still unknown like the kinematics part, which will be the topic of study in the regular mechanics course on which an outlook is provided.

2.4. Embedding in the regular mechanics course.

In this section the fourth main theme is described somewhat differently than the first three. The reason for this is that this part of the design had not been developed and tested to the same extent as the other parts. To properly develop and test a way of making use of the introductory course in the regular course would be an extensive research topic in itself (see also chapter 7). I attempted to develop some guidance in making productive use of the introductory course in the regular course, which is the topic of this section. I also investigated whether this use paid off, which will be described in chapter 6. I will start with describing the design (meaning the product, not the process), which consists of guidelines for the regular course. This will be a description of both the first and second design in one go, without a presentation of results of the first design that led to revisions as was done in the discussion of the first three main points.

Functions of the fourth main theme

The fourth main theme 's main function is suggesting suitable moments and ways of addressing specific details in the regular course, like the usual learning difficulties that will be encountered. Here the established vocabulary using terms from the explanatory scheme, which was one of the main goals of the introductory course (see chapter 3 section 2.2), can become useful.

Another function of the fourth main theme is retaining the overall perspective that the introductory course may have provided in the regular course and thereby some sense of meaning and purpose. The picture of mechanics that is sketched in the first design and that students ideally should have adopted shows the process of doing mechanics, i.e. explaining motions, as finding suitable force laws to plug into the Newtonian scheme (which has been seen to fare better according to certain criteria), which results in prediction of motion. In the second design doing mechanics was depicted throughout the course in the manner of Figure 8 from chapter 5, which shows the specification of the explanatory scheme for motion in which of course finding suitable force laws is also important. Although this overall picture of mechanics is in essence what mechanics is all about, it is seldom found in regular courses on mechanics. Regular courses in mechanics traditionally start with kinematics, involving definitions of quantities like displacement, velocity and acceleration and interpreting diagrams depicting these quantities. After that the dynamics part starts, which is mostly concerned with calculating forces, accelerations and velocities in situations with constant resultant force[9]. In the details of such calculations one can easily lose sight of what it is one is doing. The perspective of the introductory course can at such times be recalled, which widens the focus and may give more meaning to these details to students.

Link-manual

For the regular course I did not design teaching/learning activities in great detail (as described in a scenario), but made only some suggestions that were put down in a so-called link-manual. The link-manual is a teachers guide which describes how in the regular course use can be made of the introductory course, i.e. how the introductory and regular course can be 'linked', therefore 'link-manual'. One can expect that the introductory course can be helpful in understanding the mechanics in the regular course, at least that was its intention, but also that such a transfer will not go spontaneously.

[9] Such cases are the only ones that can be calculated without complicated mathematics or computer modelling.

Some effort will have to be made to affect recognition of this link. The connection between introductory and regular course can be emphasised in different ways:

- Related to the content by regularly rephrasing the content as presented in the textbook or other used teaching materials in terms of the introductory course, recall comparable topics or activities from the introductory course or even replace parts of the regular course by material from or in the spirit of the introductory course. Also discussing the inevitable learning difficulties with the vocabulary of the explanatory scheme establishes a link.
- Related to the way of working by using the same kind of teaching formats, attention to student input, or computer modelling environment the students had got used to.
- Related to the way of both formal and informal examining, testing or evaluating, by stressing the same things as were done in the introductory course. For instance laying more emphasis on conceptual questions and real understanding than on plugging and chugging formulas. Students tend to determine what is important and what not by what is on the test (and rightfully so), which means that one should test what one considers important and not what is easy to test. Osborne warned for this phenomenon when he wrote that "when we attempt to make the important measurable, only the measurable becomes important" (Osborne & Collins, 2000).

Apart from these general guidelines the link-manual contains a whole bunch of specific directions for each section or assignment in the used textbook that may be used for establishing and highlighting the link with the introductory course. The regular course following the first introductory course used a textbook by Middelink (1998) and the one following the second course used a textbook called 'Newton' (Kortland et al., 1998). I will give some examples of such suggestions related to each textbook, starting with the former. These examples are meant to show the diversity in and nature of the given suggestions.

- In the chapter on kinematics (rectilinear) motion with constant acceleration is introduced solely by describing what it is. My suggestion was to also include the dynamical relevance of such motions: these kinds of motions are the result of a constant force, e.g. gravity near the earth's surface.
- In the chapter on dynamics Newton's second law is illustrated or experimentally verified with a practical assignment concerning a frictionless cart driven by a constant force. My suggestion was to skip this assignment since the suggestion if not statement from this assignment that the second law is an empirical law is in complete disagreement with the line of thought from the introductory course. $F=m\cdot a$ is much too much axiomatic to embark on this route (Newburgh, 2001). Instead its functioning as a specification of the precise relationship between force and motion can be recalled.
- When a number of forces are introduced and illustrated, such as gravity, normal force, force from a spring, tension in a rope and three kinds of friction, most are

introduced by implicitly appealing to a rough interaction theory. For instance a spring can push or pull when pressed or extended. Normal force on the other hand is introduced by implicitly appealing to the relation between force and motion. The argument in the textbook follows the following line: *A vase is in rest, standing on a table. Therefore the resulting force has to be zero (first law). We know that gravity is working on the vase. So there has to be another force that compensates gravity. That force we call normal force.* This argument does not use interaction theory, the question 'where does the force come from?' is unanswered. My first suggestion was that some attention should be given to the sources of these forces, i.e. to interaction theory. This would recall the main project of what mechanics is all about: finding suitable force laws. Therefore learning about what kinds of forces can be found may be seen as useful. I also suggested that the two ways of identifying forces by means of answering 'where does it come from?' (interaction theory aspect of mechanics) or 'why has there have to be a force?' (relation force - motion aspect of mechanics) that were used implicitly in the textbook should be made explicit. This might also quite naturally raise the question where normal force (and also tension in a rope for that matter) come(s) from, which is a well-known problematic issue to get across (see chapter 2).

- The chapter on kinematics starts with the following introduction:

  > Motion is everywhere, take for example a speeding rocket, a riding train and an airplane or bird in the sky. Gas molecules, planets and stars move invisibly, but very fast. The growing of a fingernail and the shifting of a glacier are also motions that you cannot see. It is obvious that knowledge of motions teaches us to understand nature better. The study of motions has been the starting point of the modern sciences, for that matter. In this chapter only the motion in a straight line is addressed. This is the easiest motion we know of. (Middelink p.41)

  This expresses the relevance and purpose of mechanics in a nutshell. Motions are omnipresent, understanding motions helps us to understand change in nature (that is almost everything), and even some mentioning of the origin of modern sciences (that is Kepler and Newton among others) is made! It is a pity that the rest of the chapter does not live up to the expectations raised in this introduction, however. The chapters on kinematics and dynamics follow the traditional way of presenting mechanics. My introductory course shows what it would entail to take such an introduction seriously. I wager that all teachers using this textbook simply skip this introduction. My suggestion here was to not skip it.

Some examples of suggestions related to the second textbook are:

- The remark that a question concerning the derivation of the first law from the second is wrong.
- Related to a couple of questions about identifying forces, my suggestion was to also ask the students how they knew that the forces they identified were there.

- Two questions involved non-linear motion. One was about identifying forces on a satellite and another on a soccer ball after being kicked. The first question may trigger some memories of computer model outcomes from the introductory course. The second question can be answered in various ways. One way is as an exercise of elimination. Students simply check for each of the four forces they have come across whether it is present in the situation or not. This way focuses on the interaction theory aspect of mechanics. Another way I expect is to identify three forces, gravity, air friction and some forward force. The arguments for these forces can differ. Identifying gravity and air friction can be based on interaction theory, whereas the identification of a forward force is probably based on the relation force - motion. (For instance a remark like 'the forward force simply has to be there' indicates this kind of reasoning). After a forward force is identified based on the motion of the ball students may come up with some more or less plausible interaction theory like some aftereffect from the kick. After giving this particular expectation of student's responses my suggestions to deal with them were (again) to explicitly use both approaches from interaction theory and relation force - motion, with the related questions to discuss the given answers. For instance the identification of a forward force can be questioned by recalling that Newton did not need any forward motion to explain the motion of planets and in respect to interaction theory that Newtonian forces/influences did not show aftereffects (and did not need to).
- One assignment used a new force law for air friction ($F=C\cdot v^2$). My suggestion was that students could complete a computer model of a bicycle rider in which they have to add this particular force law.

As can be seen from these examples the suggestions varied in length and explicitness. They all tried to use some part of the introductory course in discussing, changing (or omitting) some part of the textbook/regular course and were therefore written in close connection to the used textbooks. What this also shows is the huge difference in the extent and detail of designed activities and their justification between the link-manual and the scenario (see chapter 5). It is clear that the suggestions given in the link-manual do not come close to the worked out, pondered upon and justified prescriptions of a scenario.

One important element still lacking in these link-manuals is more specific advice as to *how* the usual learning difficulties can be addressed. Some instances where they can be expected to occur have been identified and the need for addressing them has been stated, but concrete advice was not part of these link-manuals. The simple reason for this was that at the time of writing these link-manuals I did not know how this nut might be cracked. To get some more grip on this matter several interviews were conducted during the regular course following the second trial in which the usual learning problems were triggered and discussed using the introductory course. These interviews resulted in more detailed information as to how these problems might be successfully addressed. These interviews and their results will be described in chapter 6, section 8. I do not claim to have solved this problem, but I do think some useful insights were obtained that might serve as starting point for a more thorough investigation of this matter.

3. Teacher preparation from first to second design

Where in section 2 the development of the content from the first design and trial to the second design was described, in this section the development of ideas about preparing the teacher will be the topic.

3.1. Goal and problems

The problem posing character of my design calls for a rather different teaching style than most teachers are used to. Specific elements of a desired teaching style for a problem posing approach that are mentioned by both Vollebregt and Kortland include using student input and ensuring that students see the main line of reasoning. I will discuss what is meant here by both elements, thereby summarising what these two authors wrote on the subject, because this will indicate what kind of problems can be expected that the teacher preparation should somehow address.

Using student input is described by Vollebregt as 'mak[ing] pupils' own answers part of the general outcomes as much as possible, for instance by using their own expressions in summaries of the outcomes' (Vollebregt, 1998). This is important to ensure that the questions that certain episodes or activities are designed to trigger become really the questions of the students instead of the designer/teacher. Only then can such a question function as a reason for engaging in the subsequent activity, when this next activity can be expected to contribute to answering that question (on grounds that students can understand). To make student input matter the teacher should not hastily interpret students (put words into their mouths), pose suggestive questions or answer questions herself. Instead, in order to get to know what students really think, some time should be spent discussing their thought for which the teaching format of whole-class discussions is usually appropriate. However, managing whole-class discussions in a way that student input really matters is difficult for most teachers as are other ways of making student input matter.

Ensuring that students see the main line of reasoning calls for explicit attention to the transitions between activities. Although the activities are designed to follow a recognisable thread, it would be too much to ask of students to be able to recognise this thread at all times all by themselves. The teacher should help them with this by pointing out the main line of reasoning. This requires a preview of what will happen in the next set of activities that uses or builds on a reflection of what happened in the last set of activities. This is not a strictly local process, focusing only on the transition of one set of activities to the next. Also the main goal to which all activities should lead can occasionally be recalled to provide a perspective on what it is one is doing. This particular emphasis on transitions between (sets of) activities is unusual for most teachers. In traditional educational designs (standard textbooks) paying attention to such transitions would not be useful or even possible, since many transitions cannot be understood from the point of view of the students. The next activity does not follow 'logically' from the previous one irrespective of how long one would reflect on it and a preview on the next cannot be given in a meaningful or understandable way, simply because it had not been designed that way. (This is not to debunk traditional education. I am merely stating that traditional education is not problem posing.)

So the work of Vollebregt and Kortland warns for the dangers of inadequate attention to student input and inadequate attention to transitions between (sets of) activities. How can one take these dangers into account in the preparation of the teacher? This is a difficult question that still needs to be answered satisfactorily. General guidelines from the literature (e.g. (Joyce & Showers, 1988)) suggest including the elements of demonstration, practice, feedback and coaching of classroom application in teacher training. Another element that is important in teacher preparation to new material and is frequently mentioned in the literature is the teacher having a sense of ownership of the new material.

One can only practice (and give feedback on that practice and coach its application in the classroom) with some material. I did not see a useful and practical way of practicing *before* the first trial. Kortland incorporated a teacher preparation in line with the recommendations of Joyce and Showers *after* the first trial. In this way the first trial provides for the material (e.g. examples of good and not-yet-so-good practice) on which a proper preparation for the second trial can be based. For this approach the same teacher should preferably cooperate in both trials. Within one trial a teacher can of course also be realigned when the execution deviates from the plan. In such a case experiences from earlier lessons serve to adjust the teaching behaviour in subsequent lessons. However, this requires reflection on and quick analysis of these earlier lessons and allows little or no time for practicing the new behaviour or developing a teacher course addressing these specific points. Another problem is that the 'new behaviour' can still be unclear for the teacher, since it is necessarily an extension or trend of earlier behaviour. He might still not fully understand what it is the researcher wants him to change in the coming lesson, based on what was seen (and reflected and analysed) in past lessons.

Apart from the still not fully addressed problem of how to properly prepare the teacher for the first trial, there is also a practical impediment. It is hard to find some room for experimenting within the Dutch educational system. Both the curriculum and the agendas of the teachers are cramped. As a consequence few teachers are prepared to spend 10 lessons and some preparation time on something that is not directly profitable for the curriculum, let alone spend considerable preparation time.

I have taken a less than optimal execution of the first design for granted, because it can still provide sufficient results, in the sense that one can learn useful things about the design itself. This expectation is based on similar research using the same research method. In the next section I will look into the teacher preparation for the first trial. This will illustrate the mentioned expected problems, which did in fact occur (as well as some others), and show a way of dealing with these problems.

3.2. First preparation + some results leading to revision

The first design of the introductory course included both the course content and the way in which it was intended to be practically executed in class and had been written by me. The goal of the teacher preparation was to guarantee as much as possible an execution of the scenario according to plan and to adapt the scenario whenever new arguments by the teacher were convincing. The dangers of inadequate attention to student input and inadequate attention to transitions between activities were thought to be averted to some extent by including descriptions of the role of the teacher in the scenario that emphasised the importance of these particular dangers, which sometimes went as far as written-out suggestions for how to address certain transitions. A sense of ownership was thought to be instilled in the teacher by explaining all considerations in the designing process and using as much as possible his input and suggestions for modifications in the design. This anticipated a rather active interest in the designing process from the teacher. In retrospect this ‘instilling ownership by convincing’ as well as my anticipation of active interest in what is basically my job seems somewhat naive.

The preparation of the first teacher took place in three phases. The first phase consisted of one meeting of about two hours in which I presented the course as a whole together with its basic ideas to the teacher. In this way the teacher could get an overview on the basis of which he could decide if he wanted to cooperate or not. The second phase consisted of four sessions of approximately two hours each in which each part of the course was presented and discussed in more detail. In the third phase each lesson was extensively discussed one or more days before the lesson took place and shortly evaluated the same day the lesson took place. The communication was pretty much an unidirectional process in which I explained and emphasised what I thought were important points in the scenario. The only indications at that time of what the teacher actually understood, agreed with and remembered were his questions and suggestions during these meetings. This was the best I could do at the time.

Apart from the general difficulty that with a unidirectional way of communication it remains uncertain whether all intentions and meanings of the design are understood, some experiences during the first trial indicated two problems with preparing the first teacher. The first problem was that good introductions and evaluations for activities and proper attention to student input was frequently lacking. Vollebregt and Kortland reported the same problems, as we saw, and these were therefore not unexpected. However, the real importance of these problems (or dangers) they warned for, in a problem posing design had been underestimated by me. Only after experiencing these problems myself up-close in the first trial, I realised that the advice given in the scenario related to the teacher’s role and also in the discussion of the scenario during the teacher preparation lacked sufficient clarity and emphasis. There is a difference between being aware of and warning for a problem and *really* realising its crucial importance. Metaphorically put: Although I thought I knew that a candle can burn one’s finger, I still had to burn my finger in order to really appreciate this fact.

The second problem, which is related to the first, was that the design asked for a ‘content driven’ teaching style whereas the teacher was used to a ‘procedure driven’ style. With this I mean that students should be led by the train of thought that develops during the course instead of procedural guidance like indicating relevant page numbers, section numbers, which assignments should be finished by when et cetera. The problem was not so much the attention to procedure. There is nothing wrong with procedural guidance as long as it does not eclipse the content. The problem was rather the lack of attention to the line of reasoning.

I will first illustrate the problems with some examples and then present a not fully successful way of remedying them during the first trial. A possibly more successful approach will be discussed later, after which the opinion of the teacher on the preparation will be presented.

Illustration of some problems relating to teacher preparation

Example 1: lacking proper introduction and evaluation and not using student input

A motion on earth is investigated as an additional way to say more about the value of Keplerian and Newtonian models, which in the previous activity were seen to lead to comparable results in the case of motions of heavenly bodies. The teacher introduces this activity without using student input.

1. T: The next step. We have seen that with this whole thing model and observation can be matched very well with ‘p’[10] two, with Newton. With Kepler it succeeded reasonably, so it is still not so clear to say ‘the one law we can adopt immediately and the other law is completely wrong’.
2. T: Therefore we will look at some situations like [how] it is on earth according to Newton and according to Kepler.
3. T: We will continue with the next assignment, the assignment 19, 20 and 21 of section 1.12. We are to work on that ourselves and the part we do not finish [in this lesson], we will finish before the next time. If there are some problems with this, I hope to see more often people in the z-lessons[11] than before, for I noticed from the first part of the lesson that some of you have not yet understood how things work.

In (1) the teacher evaluates the preceding activity by drawing a conclusion. Students were meant to arrive at this conclusion, but it remains unclear if they did, because they were not asked what their conclusion was. Even when they did, the conclusion here can not be recognised as verbalising the students’ conclusion. Building on the teacher’s conclusion it may make sense to further investigate the two types of models in situations on earth. Here the teacher simply states that the students will look into situations on earth (2), without mentioning its relation to the evaluation of types of models. I do not expect students to be able to understand why this new direction is taken, since it is not mentioned and quite hard to think of themselves. They cannot at this time recognise the investigation of models on earth *as* an application of the intuitively clear criterion of broad applicability for valuing these types of models. The next assignment is then introduced in a procedural fashion, without relating its content and goal to the previous one (3).

[10] p indicates the power of the distance between sun and planet r, see section 2.2.1.
[11] Lessons used for self-study in which students can opt to see teachers for clarification.

Let us hypothesise for a moment what might have happened, because this can illustrate what I mean by a transition that uses the previous activity to introduce the next. Even without explicitly using the criterion of broad applicability students might be expected to follow the teacher's train of thought *when they can have some part in it*. When they feel committed to their conclusion (not the teacher's) that the two models are still in the race, they may feel more willing to think about a possible further way of investigation and, given some time for discussion, even come up with a suggestion in a direction that can be massaged by the teacher towards investigating other motions (e.g. motions on earth).

Example 2: Attention to process instead of content

The following example is typical for one of these moments in which the teacher puts students to work. As mentioned in chapter 3 section 4.1 footnote 9 I expect that most people involved in education will recognise the phenomenon. The particular topic (here dimensions of the solar system, which was a side issue in the first design and therefore not mentioned before) is of no concern. The point is the way it is introduced.

> T: We will continue with section 1.7 the dimensions of our solar system. It is good that when we are going to explain something on the solar system later on, that we have some notion of the dimensions. For assignments 5, 6 and 7 we will need Binas[12] and drawing compass and a sheet of paper, which I will distribute shortly.

Although something is said about the reason for these assignments, namely that some notion of dimensions will prove useful for a later explanation, this seems not very convincing. For instance the question what this explanation will be about needs to be answered before this reason can make sense. Furthermore the given reason is completely drowned by procedural details about which assignments (5, 6 and 7) are to be done in what way (by ourselves) and with what tools (Binas, drawing compass and sheet of paper). The fact that in this example both some reason for the content and procedural things are addressed makes the ineffectiveness of the content part even more striking, I think. I do not want to downplay the importance of good procedural instructions (although too much can become somewhat patronising), but this shows how it can overshadow attention for course content and reasons to engage in such content.

An attempt to remedy the problems

The scenario was lacking in sufficient indications for the teacher as to how an introduction that builds on students' input could be given. The importance for such indications became more apparent after experiences such as the one in example 1. An idea used in the first trial to pay more attention to these identified important transitions between activities was expressed as a need for so-called 'moralising talks'. I thought that what was lacking were moments in which the teacher told the 'moral of the story', mainly when going from one activity to the next. At those moments a 'moralising talk' from the teacher should explicate the logic of the course, i.e. indicate why the next activity follows the last one. In the preparation for the remaining lessons of the course I

[12] A standard schoolbook mainly containing tables.

indicated these moments and made suggestions for what these 'moralising talks' might entail, which the teacher made notes of.

The next example illustrates one of these moralising talks. Here the teacher starts the third lesson by looking back on the second:

1. T: In the second lesson we encountered a difference of opinion concerning the basketball player[13]. We might remember the question: without influence, how will the ball continue? One said the ball will move straight on, another said the ball remains floating, another said the ball will go down and we also heard the ball has no specific direction.
2. T: There was a similarity in the talk about motion. That we called the explanatory scheme. The explanatory scheme had two aspects: How is the influence free motion, the first aspect and the second aspect: which suitable influence explains the deviation from this influence free motion.
3. T: We probably remember the formula 1 racing car and the little ball moving along the tube. Was it or was it not continuing in a circular trajectory? At home we read the texts on Kepler and Newton. Has anyone got questions about that? ...

The teacher starts this introduction in the way we prepared, making use of student input by referring to some notions that had actually surfaced in lesson two (1). Although he was reading from his notes, at this stage the students actually appeared to follow him and recognise the examples he named. He then explicates the explanatory scheme, but (maybe because he is just reading notes) in such a condensed form, that it can be expected to be only comprehensible for those already very familiar with it (2). Here I observed in the classroom that the students appeared to begin to lose interest. The teacher somehow forgets another point that should have been addressed at this stage concerning the similarities between the way the students explained motion and the way Kepler and Newton did, namely that both students and Kepler and Newton differed in their assumption for an influence free motion and both used the same explanatory scheme. This was intended to provide for a bridge to the next topic of (reading texts about) the notions of Kepler and Newton. Instead he continues with addressing these texts directly, without their relation to the preceding lesson (3).

This example shows that preparing the teacher by identifying those moments for, and suggesting the content of, moralising talks works to some extent, namely that at least some attempt is made to introduce the next activity by using actual student input from the preceding one, but that it also leaves much to be desired: in this case the main element was missing, reading from notes is not the best way to involve students in your train of thoughts (for it tends to be too condensed and unappealing) and referring to student input would be even better when some names can be mentioned (although it appeared that some students recognised their answers in the way the teacher put them). The strict adherence to the notes by the teacher also suggests that he found the moralising talks difficult enough to not trust himself to be more free and spontaneous about them. This difficulty was not unexpected given the experiences by Kortland reported earlier. Making the kind of transitions between episodes the design calls for *is*

[13] One of the video fragments.

difficult. The used approach of indicating moments for and suggesting the contents of moralising talks did not suffice in addressing this difficulty.

The teacher's opinion

In an interview after the introductory course I asked the teacher how he considered the preparation. He said that he found the first phase not useful. The sessions in preparation of each lesson he appreciated the most. The concrete students booklets (which were only ready after phase 2) provided him with the most useful information, he said. His opinion of the unidirectional character of the preparation was that he thought this was quite efficient. An alternative in which he would think of a practical execution would take much more time, was his estimate.

Related to the trial as a whole he had two main concerns. The first was the amount of time the course plus preparation had taken him. In addition to the three phase preparation he had spent about an hour preparing each lesson going over notes of our discussions, scenario and student booklet. The second concern was that the way of working in the course had not been in line with recent educational developments (Dutch: tweede fase) in which more emphasis is put on students working independently. He affirmed that he would prepare in the same way if he could repeat the process.

The teacher preferred not to collaborate in a second trial. His reasons were that he would like to wait to see the effect of the course on the regular course. If he had to speedily work his way through the regular course material, not noticeably benefiting in time from the introductory course, this would be unsatisfactory for him and the students. Since I needed an answer from him straight away, he declined. Further reasons he mentioned were that the financial settlement left room for some irritation and that he would like to wait to see at which time in the day he would have to teach the class in the second trial. The latter argument was triggered by the fact that this teacher taught a different subject to the same class late in the afternoon instead of early morning at which the first trial took place. He noticed a huge difference in the ease at which the class could be 'motivated'[14]. He was therefore reluctant to teach an experimental course late in the afternoon. I also thought it best to stop our collaboration.

3.3. Ideas for second preparation: interaction structures

The problems encountered with the teacher preparation in the first trial indicated four points of attention, to recap: attention to student input, the importance of proper introductions and evaluations and related to that the focus on content instead of procedure, getting the ideas and meanings of the scenario across, and instilling a sense of ownership. An unsatisfactory aspect of the preparation of the first teacher underlying some of these problems was that it was mainly unidirectional. To make the teacher more actively involved in the preparation he could be asked to design the practical implementation of the structure of the introductory course. Its content as was summarised in section 2 had already been developed, but how this can be best implemented still leaves a lot of room. For example, when the design argues for students having to think about some question, this can be done in a number of ways.

[14] The word he used was 'motivated', which here means 'getting the students to work', I think.

Students can read the question, the teacher can pose the question, they can write their personal answer down, they can discuss the question in pairs or small groups, the teacher can give the answer himself, to name but a few possibilities. Designing these details of the practical application in collaboration with the teacher who would execute the design could make the teacher not only familiar with, but also actively involved in the already designed product. This would give the teacher a sense of ownership of the final design and would provide me with (written) concrete material to check in what way the teacher had understood the aims and meanings of the course structure and content. Furthermore, since these practical details concern normal teaching stuff I could draw on the experience of an experienced teacher. Filling in these details are a teacher's cup of tea.

The teacher should be guided in his designing of the practical implementation in such a way that the indicated problems of proper introductions and evaluations of (sets of) activities and using student input are explicitly addressed. To emphasise the importance of these points and to present the teacher with some designing tools that make them explicit I proposed the idea of using interaction structures. I will first describe in rather general terms what is meant by interaction structures and then indicate how they were used in the preparation of the second teacher.

The general idea of interaction structures

Interaction structure is a term coined by Westbroek that can be roughly translated as teaching method or instructional format, but adds to these meanings an emphasis on the way people (teacher and students) communicate. It is inspired by Lemke (1990). Lemke analysed interactions between teacher and students in science classes and came up with recurrent patterns he called 'dialogue structures' such as 'triadic dialogue', which Lemke describes as a teacher dominated monologue.

The triadic dialogue according to Lemke follows the following sequence of elements, with the three elements printed in bold being characteristic for this structure and the elements in parentheses being optional:

	(teacher preparation)
Triad of moves: 1.	**Teacher Question**
	(teacher call for bids)
	(student bid to answer)
	(teacher nomination)
2.	**Student Answer**
3.	**Teacher Evaluation**
	(teacher elaboration)

His message was that much of the interactions in science classes do not promote students to 'talk science' as much as he would like. Student input does not really matter, but is mainly used to further the teacher dominated monologue or as a tool for class management. The basic feature that can be recognised in all his dialogue structures is the recurrent pattern of an introduction, main question, answer and evaluation. In the presented example of triadic dialogue the introduction consists of a teacher preparation.

The main question consists of the teacher question and call for bids. The answer consists of the student bid to answer, teacher nomination and the actual answer. The evaluation finally consists of the teacher evaluation and elaboration.

Westbroek's idea was to work this recurrent feature in several so-called 'interaction structures' as a tool to specifically address the importance of properly introducing and evaluating one or more related activities. The name interaction structure is used to distinguish it from the dialogue structures of Lemke. Apart from their other purpose (in emphasising introduction and evaluation), the difference lies in that interaction structures describe a longer time span. Whereas dialogue structures typically describe interactions ranging from several seconds up to several minutes, interaction structures range from about 30 - 80 minutes, the size of an episode as described in section 1[15].

In the introduction of an interaction structure the main question is introduced in one or more activities in light of the preceding activity and the final goal to which the various activities, episodes, main themes or course should lead. The main question is then posed and answered in several coherent activities. Their coherence lies in the fact that they all contribute to answering one main point of the course content. This part can of course contain many questions and answers, but they all are meant to contribute in answering one central question that expresses the goal of the episode. The evaluation then looks back to the activities related to the introduction, the main question and its answer, also in one or more activities. Here answers are collected, made explicit, evaluated, refined, elaborated and sometimes added to, resulting in a completion of answering the main question in accordance with how it was introduced.

I will now present a short list of interaction structures that will be seen to occur in my design, which will be presented in the next chapter. The basic form of any interaction structure is depicted in Table 4.

Basic form	
Introduction	The teacher bridges the content related outcomes of the prior learning activity with this successive learning activity.
Main Question	Teacher (or textbook) asks for students' opinions or answers concerning the main topic of this set of activities.
Answer	Students produce (written) answers.
Evaluation	Answers are collected, made more explicit, elaborated and evaluated in light of the introduction. The outcome is then linked to the introduction of the next main question / interaction structure.

Table 4: Basic form of interaction structures

Two interaction structures that recur many times in my design, I call 'taking stock' and 'concluding', see Table 5 and Table 6.

[15] Lemke uses the term 'episode' differently. A more substantial discussion of the relation between interaction structure and 'episode' in the way described in section 1 will follow shortly.

Taking stock	
Introduction	The teacher bridges the content related outcomes of the prior learning activity with this successive learning activity.
Main Question	Teacher (or textbook) asks for students' opinions or answers concerning the main topic of this set of activities.
Answer	Students produce (written) answers.
Evaluation	The purpose of the evaluation is to arrive at a conclusion, which is expected to surface quite easily from students' answers (when this is not expected the I.S. 'concluding' is more appropriate).
Introduction	The teacher (or material) gives some perspective on the goal and meaning of the evaluation.
Inventory of answers	The teacher points out one or more students to give their answer.
Evaluation	The teacher evaluates the answers by comparing them to the intended answer. If the answers don't meet the criteria, he/she can elaborate with follow up questions
Clarification/ Elaboration	If an answer is not clear, the students or teacher can ask a student to further clarify her answer (For example: 'what do you mean by… ?').
Addition	If some minor aspect in the answers is still missing the teacher can add it him/herself.
Summary	The teacher summarises the answer and proceeds by linking these outcomes with some short remarks to the preparation of the context of the next question.

Table 5: Description of the interaction structure 'taking stock'

Concluding	
Introduction	The teacher bridges the content related outcomes of the prior learning activity with this successive learning activity.
Main Question	Teacher (or textbook) asks for students' opinions or answers concerning the main topic of this set of activities.
Answer	Students produce (written) answers.
Evaluation	The purpose of the evaluation is to arrive at some conclusion, which is expected to be difficult to surface without help (when this is not expected the I.S. 'taking stock' is perhaps more appropriate).
Introduction	The teacher (or material) gives some perspective on the goal and meaning of the evaluation.
Inventory of answers	The teacher points out one or more students to give their answer.
Evaluation	The teacher evaluates the answers by comparing them to the intended answer. If the answers don't meet the criteria, he/she can elaborate with follow up questions.
Clarification/ Elaboration	If an answer is not clear, the students or teacher can ask a student to further clarify her answer (For example: 'what do you mean by… ?').
Addition	The teacher him/herself can add some aspects in the answers that are still missing. Or, when such an addition is very substantial, at this point new activities concerning such an addition can be introduced.
Summary	The teacher summarises the answer, including his addition, and proceeds by linking these outcomes with some short remarks to the preparation of the context of the next question.

Table 6: Description of the interaction structure 'concluding'

The difference between 'taking stock' and 'concluding' is the emphasis and implementation of the evaluation phase. In taking stock it is expected that the intended answer to the main question of the set of activities fairly easily surfaces from some student answers. Some of these answers therefore only need to be made explicit, requiring only slight clarification, elaboration or addition. The conclusion or answer simply and understandably, but not automatically, follows from these few examples of student responses. The teacher is needed to ensure that the answer to the main question surfaces with enough clarity and emphasis and in close relation to the student input.

In the case of 'concluding' it is expected that more work needs to be done to arrive at the intended conclusions from the answers of the students. In this case these answers still need to be made explicit and evaluated, but also substantially clarified, elaborated and added to by the teacher. Where the evaluation in 'taking stock' might take a short class discussion of two minutes, the evaluation in 'concluding' may involve a class discussion of up to 15 minutes or so, which can even include group discussions of clarifying questions or other activities leading up to the central conclusion.

The difficulty or 'weight' of the evaluation can be considered to lay on a scale ranging from very easy or 'light' to very difficult or 'weighty'. An example of an evaluation on the light end of the scale would involve merely checking whether students had found the correct answer to a problem. Here merely repeating the answer would suffice (carrying the implicit message that this answer is in fact right, and all students should write it down, e.g.). There is no sharp distinction between taking stock and concluding. Within taking stock the input of the teacher can already range from little to some effort. I drew the line where I expected the evaluation to take more than about 5 minutes. (More than 5 minutes indicating 'concluding', less indicating 'taking stock').

The well known teaching format 'thinking - sharing - exchanging'[16] can also be described as an interaction structure, see Table 7.

Thinking - sharing - exchanging	
Introduction	The teacher bridges the content related outcomes of the prior learning activity with this successive learning activity.
Main Question (Thinking)	Teacher (or textbook) asks for student's opinions or answers, specifically addressing every student. All the students in class need to write down their answer.
Answer	Students produce individual written answers
Evaluation (Sharing)	The students are asked to compare their individual answers in groups and produce one 'group answer' to an assignment, which builds on the first, providing a 'deeper insight'.
Introduction	The teacher gives some perspective of the way in which the individual answers require 'deepening', thereby providing for a reason for 'sharing'.
Question	Groups are asked an additional question, which uses/builds on the individual results, but also calls for deeper insight.
Sharing	Students share their individual answers in groups.

[16] The name may be less well known than what it stands for. I surmise that most people involved in education will recognise this format.

Evaluation	The group members elaborate on each individual answer, thereby addressing differences and similarities. And by doing that, the group tries to identify the key features of the problem.
Clarification/ elaboration	If an answer is not clear, group members can ask for clarification. If an answer is superficial, group members can ask for additional information.
Negotiation	Group members negotiate about what the group answer should be. Every group member must agree.
Conclusion	The group writes down a group answer
Evaluation (Exchanging)	The group answers are compared in class producing one 'class answer', which provides for an even deeper insight.
Introduction	The teacher gives some perspective of the way in which the group answers require 'deepening', thereby providing for a reason for 'exchanging'.
Question	All students are asked an additional question, which uses/builds on the group results, but also calls for deeper insight.
Exchanging	The teacher points out one spokesperson for each group and asks each spokesperson to express the group answer.
Evaluation	The teacher evaluates the group answers by comparing them to the intended answer.
Clarification/ elaboration	If a group answer is not clear, the students or teacher can ask a group to further clarify their answer (For example: 'what do you mean by ...?'). If an answer is not complex enough, the students / teacher can ask for further information.
Negotiation	The teacher formulates or let a student formulate the class answer and asks the class to respond.
Addition	The teacher can add some missing elements to the developing class answer.
Summary	The teacher summarises the content related outcomes embodied in the 'one best class answer' and proceeds by linking these outcomes with some short remarks to the preparation of the context of the next question.

Table 7: Description of the interaction structure 'thinking - sharing - exchanging'

This interaction structure is more complex and carries the implicit message that the main question is a difficult one[17]. Let us look in some detail into the relation of interaction structure and episode. Both episode and interaction structure indicate a coherent part of a course. Dividing a course in coherent parts can be done from the perspective of the content and from the perspective of the form in which the content is shaped, i.e. the way the content is addressed. From the perspective of content a course can be organised in a series of subsequent main topics or questions or points or goals. Each topic can be said to have some main goal, which can be stated as answering some main question. The difference here is merely linguistic. The term episode is used here to indicate a part of a course that concerns one particular main question and its answer (and is therefore related to the content perspective). This already establishes a 'grain

[17] Various interaction structures carry various implicit messages about the difficulty of the topic and the kind of answer (opinion, recalled fact, pondered upon conclusion et cetera) that is expected of students. These messages should be in accordance with the goal and function of the set of activities. See for a discussion of this relation (Westbroek, 2005).

size'. An episode is not longer than what is needed to address some question and not shorter than what stating and answering such a question would entail.

From the perspective of the way topics are addressed a course can be organised in a series of interaction structures. The grain size of episodes fits the grain size of interaction structures or in other words: both perspectives on dividing a course in parts suggest the same size for these parts. In this respect the two fit nicely. There is a more fundamental relation, however. Of course the content implicitly suggests one or more appropriate ways of addressing the content, i.e. the content suggests an interaction structure. This also works the other way around: the interaction structure implicitly suggests the difficulty or importance of the content. A more elaborate interaction structure (like 'thinking-sharing-exchanging') already carries the message to students that the topic will be difficult. In this way episode and interaction structure are two sides of the same coin.

Thinking about a suitable interaction structure for some given episode forces one to answer important questions relating to both content and the way to address it. This thought process is somewhat guided by filling in a scheme for an episode such as depicted in Table 7. It makes one think about all interaction aspects that are needed and can be expected. In this way one is likely to consider didactical questions like: Why choose this interaction structure? What answers do I expect? How am I going to respond to these answers? Why respond in that way? How does this serve the educational goal for this activity? (What is the educational goal for this activity?) How can I wrap up the activity in such a way that does justice to what the students have said? I content that a choice based on such a thought process results in more quality in teaching than a choice that simply seems suitable or is 'based on experience' (that is: habit). One could conclude that some aspects, for instance the elaboration, will not be necessary, but this conclusion is then at least the result of some thought.

This concludes my rather general description of the idea of interaction structures. I will now turn to the topic of how these were used in the preparation of the second teacher.

Using interaction structures in preparing the teacher

From the previous part of this section it may have become clear that asking the teacher to design the practical implementation of the already designed content of the introductory course using a set of interaction structures practically forces him to explicitly address the issues of proper introduction and evaluation and use of student input. I intended to present him with a few interaction structures in the form of tables like Table 7. He could be presented tables of 'thinking-sharing-exchanging', 'taking stock', 'concluding' and one or two variations on these structures. I could then ask the teacher to write down a plan for the practical implementation of the designed content presented to him in a proto-scenario and which could be discussed together. The plan was that these discussions of the content follow a similar phase structure as was used in the preparation of the first teacher, except that a more two-way communication could be attempted in the third phase of the preparation of the second teacher. The goal of this phase was to arrive at a finished design of the practical implementation of the already designed content and therefore a complete scenario.

The teacher would choose and fill in interaction structures for all episodes in the third phase. In that way I could read the resulting practical implementation of the already designed course content and get a good impression of what he had understood of the meaning and intentions of the course content. On the basis of this we could then further discuss possible misunderstandings and the choices for the practical implementation that were made, especially whether the way main questions were introduced and evaluated in accordance with the goals and functions of the various episodes. I expected the teacher to be ready and able to do this, since thinking about interaction structures resembles thinking about teaching methods, which teachers do all the time. The main difference now being the explicitness of the thinking and the stronger emphasis on the introduction and evaluation of each episode.

I did not use other experiences from the preparation of the first teacher in the preparation of the second. One might think that for instance fragments (either video or written out audio) indicating the mentioned problems may make the second teacher more sensitive to these problems. In retrospect I think this might have been a good idea. At the time this was considered unnecessary for three reasons. Firstly, the second design was so different from the first that that it would be difficult to find proper fragments that had sufficiently recognisable bearing on the second design. Secondly, the problems in the first teacher preparation were considered at the time to be quite strongly related to his particular teaching style. The second teacher was selected (among other things) for his teaching style that was considered to be more in accordance with the design. It was therefore expected that the problems from the first preparation would not surface to the same extent and would therefore be less urgent. Thirdly, the practical restrictions in time and the choice for prioritising the design for an introductory student course, instead of a teacher course (for his preparation) left too little time for thoroughly using the experiences from the first preparation.

4. Concluding remarks

In this chapter the development from the first design to the second design has been described. It was seen that although the first design seemed quite doable in the sense that a rather convincing justification could be given for it, it still showed several shortcomings when put to the test. Many of these shortcomings were discussed and could be understood in retrospect. This does not mean that the first scenario was prematurely tested, although it might have benefited from more thought. Instead it shows that testing a scenario is the way par excellence to find out in which manner the design can be improved. Both elements, testing and a scenario, are needed in order to learn in what way the design needs revision. This chapter can be seen as an illustration of the method of design experiments at work.

The second main topic of this chapter was the preparation of the teacher. Here a picture was presented of the difficulties involved in such a task, for which a fitting solution has yet to be found (if there is any). A possibly fruitful step in the right direction seems to be the idea of using interaction structures, which has been presented in some detail.

The description of the design as given in this chapter is quite broad, although sometimes some details have been presented for the sake of clarifying the broad description. In the next chapter I will zoom in upon this broad description and will present the scenario on the intermediate level of episodes and the detailed level of activities.