Chapter 6

Results

1. Introduction

In this chapter the analysis questions are answered. For this the executed teaching/learning process is compared to the intended teaching/learning process as written down in the scenario (chapter 5). For each episode I will describe what happened in the introduction, main question and answer phase, and evaluation, insofar this is relevant for answering the analysis questions as stated in chapter 5, table 1, 2 and 3. I will then answer these questions and finally draw some conclusions regarding the episode and discuss possible improvements in the design of the episode. After all episodes within the first main theme (section 4) have been treated in this way I will draw some conclusions regarding this main theme. The same process is then repeated for the second and third main themes in sections 5 and 6 respectively.

The choices for interaction structures will be discussed in a separate section, section 7, instead of including it in the discussion of each episode, because that would involve too much repetition.

Section 8 contains an account of main theme 4, embedding in the regular mechanics course, for which advice in the form of a link-manual had been given. Here some results of and experiences with the link-manual are reported. Additional information concerning possible use of the introductory course in the regular course was obtained from interviews during the regular course in which mechanics problems were discussed using elements of the introductory course. The design and results of these interviews will be presented here.

Before showing the results of the introductory course, I will present the results of the preparation of the teacher in section 3 and start in section 2 with a more concrete description of the methodology including the kind of data that were collected, how they were analysed and how they will be presented.

The evaluation of classroom practice in this chapter includes sometimes rather critical comments on the design itself but also on the execution of the design by the teacher. These comments resulted from a cool analysis of the classroom practice from behind a desk in the quiet environment of a university building long after the heated confusion and hustle and bustle of a normal secondary school[1] in which the lessons took place. The teacher had to execute the scenario, manage his class and all intrusions from colleagues and other students and decide in the spur of the moment how to react to what happened in line of the scenario and all other considerations. The fact that the scenario was and is still in development and therefore lacked in clarity did not help. The critical comments in this chapter should therefore not be seen as criticism of the teacher personally but of the teaching/learning process as laid down in the scenario and as criticism of the way the teacher was prepared.

[1] People who happen to visit both kind of places know that the differences can be striking.

2. Methodology

In addition to what I said about the used method in chapter 3, section 3, I will present here more concretely what data were collected, how they were analysed and how they will be presented in this chapter.

Data sources and collection

The whole class sections of each lesson were video taped. The teacher and researcher carried an audio recorder at all times, recording all teacher - student or researcher - student interactions. Furthermore student - student interactions during group work (or work in pairs) were recorded on audio. Since the class consisted of only seven students (five girls and two boys), this amounted to not more than five or six (1 teacher + 1 researcher + 3 or 4 pairs) audio tapes per lesson. After each lesson students' written materials were photocopied. Each lesson was shortly discussed with the teacher before and after the lesson of which no recordings were made. Finally, I made notes of my observations in each lesson. In all, this is a plethora of data. After the introductory course students filled in a questionnaire about how they had experienced the course. I also conducted two different kinds of interviews afterwards. The first concerned students recognition of the main thread of the course and consisted mainly of questions like 'why did we do this particular section?' and 'why did we do this after that?' The second kind of interview aimed to find indications of recognition and application of elements of the introductory course in the regular course.

Data analysis

The scenario was an important tool in the analysis, for it contained the means to compare the observed teaching/learning process to the expected one, which was written down in the scenario, and the analysis questions and therefore guided the determination of what data was relevant and what not. For each episode several analysis questions were formulated, see chapter 5. I tried to answer these questions using the available data, which were organised in so-called 'lesson reports' to facilitate this. In these lesson reports possibly relevant discussions between teacher and students or between students among themselves were transcribed. Also students' written answers were summarised. Furthermore they contained my observations and preliminary comments on possible interpretations, relevant examples and first rough conclusions. Lesson reports can be seen as somewhere in between raw data and the results presented in this chapter for which they provided the basis. Lesson reports resulted in an average of 24 pages for each lesson with a total of 13 lessons including one lesson spent on a test, which is reduced in this chapter to about 45 pages. More on the presentation and selection of data follows in the last part of this section.

Answering analysis questions using the mentioned lesson reports amounted to first selecting the relevant episode in the lesson reports (and sometimes also data from one of the two interviews after the course), then comparing these data to expected responses and comparing different sources, for instance students' discussion of, written answer to and teacher help given in, some particular assignment. Using different data sources adds weight to one's interpretation, for obvious reasons.

My answers to the analysis questions were read by a second researcher who had access to the lesson reports and who went through the process of selecting and interpreting relevant data from the lesson reports in order to arrive at answers to a subset of analysis questions. In discussing these interpretations and answers we usually reached agreement.

A big problem in this process was when the execution of the episode deviated strongly from the design. In those cases it was much harder to arrive at sound conclusions about the scenario, since the intended design was not fully put to the test and only very tentative answers to analysis questions could be given.

Data presentation

Not all data on which I based my conclusions can be meaningfully reported here, for obvious reasons. I will present those findings that I deem sufficient for an interested reader to be able to follow and possibly (dis)agree with my conclusions, or at least allow raising in this reader the right kind of (critical) questions.

In my description of the results of the first couple of episodes I will use an abundance of examples to give the reader some impression of the sort and amount of data on which my conclusions are based. In later episodes I will restrict myself more to the findings themselves, only illustrated by one or two typical or merely illustrative examples[2] from the original data sources. My choice of examples was also checked by another researcher who had access to the lesson reports and was intimately acquainted with the design. Only those examples we reached agreement on were used in this presentation of the results.

3. Teacher preparation

How I intended to prepare the teacher was described in chapter 4, section 3.3. In this section I will describe some deviations from that plan insofar they have a bearing on the *results* of the preparation, which is the main topic of this section.

The teacher preparation went according to plan to the extent that the teacher was prepared in three phases, of which the third and most important phase consisted of about eight sessions of approximately two hours each. (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. 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

[2] With a *typical* example I mean an example that is representative for the majority of instances which the example illustrates. Another example could have easily been selected, since it would show the same point. An *illustrative* example is an example that clearly shows a particular point I try to make and does not carry the burden of being *typical*. 'Illustrative example' is of course a strange way of putting things, since all examples mean to illustrate something. However, it is used here to distinguish it from 'typical example'.

detail.) In this phase the scenario as well as its practical implementation were discussed in detail. I intended to use interaction structures in the teacher preparation as a tool for designing the practical implementation part of the scenario for a number of reasons, amongst which making the preparation more two-directional, but unfortunately the teacher rejected the idea. I could not convince him of its use for improving the quality of the designed education. He did see the use for me as a researcher, but not for him as a teacher. That was not enough to engage in what he considered to be a gruelling job. His rejection is quite understandable. It *was* a difficult and time consuming job for which he did not see the purpose. At the time I was unable to make him appreciate the dangers of the experienced problems from the first trial (which were similar to those reported by Kortland (2001)). A for the teacher recognisable purpose would have consisted of some experienced shortcoming in his teaching for which the method of filling in interaction structures could be seen to provide a remedy. Firstly there was no experienced shortcoming in his teaching. He was by all normal standards of teaching a very good teacher of the usual courses he taught. The newly designed introductory course in mechanics he had not taught yet, so he could not have experienced any shortcomings there either. Secondly it is not self evident that the method of using interaction structures in the proposed way would remedy a possible teaching problem in the new introductory course. It can be argued that it does, but these arguments probably are only convincing for those that have experienced the problems, like I did in the first trial.

Although the teacher did not accept my proposal to write down a design for the practical implementation of the course content in terms of interaction structures, he did write a description of the implementation, which consisted of a very briefly stated lesson plan. In order to complete the scenario in which the practical implementation was still lacking, I used his description as a basis for filling in the interaction structures myself and adding those to the scenario. In the third phase we discussed the in this way completed scenario in detail. Given the extensive additions and changes I have made in the teacher's lesson plan that were necessary for filling in the interaction structures, my original goal of instilling some sense of ownership in the teacher is probably not met. The teacher's lesson plan gave very little feedback as to what had been understood about the meaning and intentions of the design. However, although substantial written feedback was lacking, the discussions of the scenario in the second and third phase of the teacher preparation were naturally more two-directional for the simple reason that the second teacher found the ideas behind the scenario and the scenario itself quite interesting and was therefore more actively involved in their discussion. From these discussions I got the impression that this teacher understood the main points as well as the details. However, such an impression is rather unsure. Written feedback in the form of a design for the practical implementation would have been a much more solid indication of what has been understood by the teacher.

The goal of arriving at a complete scenario including the practical implementation was met. We could therefore start testing a scenario that was pondered upon and justified in much detail, but with a teacher of whom it was not certain if he shared the meaning and intentions of the design and who did not own the design to the extent that was possible or desirable.

In the subsequent sections I will describe what results the various episodes brought.

4. The how and why of explaining motion

The following sections, section 4.1 through 4.5, concern the results related to the first main theme, the how and why of explaining motion. Each section starts with a description of what happened, followed by the answers to the analysis questions and ends with a conclusion on the level of episode and possibly some suggestions for improvement of the design. The analysis questions can be found in chapter 5, section 2 and will be numbered here accordingly from 1 through 25.

After the last episode of this main theme some conclusions on the level of main theme will be drawn. This structure is then repeated for the second and third main theme.

The reader may find it helpful to consult the episode descriptions in the scenario and the related analysis questions from chapter 5 when reading the following sections.

4.1. Episode 1.1: Introduction to the topic of mechanics

What happened?

One aim of the introduction was to enthuse the students. This the teacher seemed to have made happen, though perhaps more by his way of presenting than by what he said. At any rate, the students listened attentively. Concerning the content of the introduction let us look at the relevant fragment. (In the rest of the introduction the students are reminded to bring certain materials with them and a space shuttle accident is further discussed, leading to a discussion of dinosaurs, which is irrelevant for the function of this introduction).

1. T: We are going to talk about motion. What is motion? How does it work? How is it put together? Well, we know how motion is put together, don't we? Why something moves. Do you know that?
2. Car: Well, to go on.
3. T: Yes, but how can something go on? Or, and we proceed by following two people of very long ago when this all, when they thought, yes, not knew exactly how things were put together, with motion. And what you then have to do, of course, is think of some kind of theory. You have to think of, I think it 'll work in this way, and that you develop somewhat. Well, if you do one theory, you always think: this is it, of course. That's why we do two, of two different people who had different ideas and which we will, yes, 'think through'. Think through in the sense of think in the same way as they had done. From the same starting points. And we changed it a little and adapted it a little,
4. T: for it does not really concern these two people, that is also rather funny to know, but they are Newton and Kepler, which is not really the main point. The main point is what have they come up with? And how can you come up with these things? So you have to think of some theory and then check if it works in practice and we will do that using motions in the solar system. Why solar system? Well, that is what they started with too. It is of course very strange that the sun turns around the earth, or the other way around. And that it, yes how does it work? How can it be that that happens? And why does it happen in that way and not differently? They

came up with all kinds of thoughts on these things and that is what we are going to do too. [...]

5. T: […] Something moved in space recently, that went slightly wrong. What was that? Did something go wrong in space recently?
6. Lln: Space shuttle.
7. T: Yes. […]
8. T: How can that be? What could have gone wrong?
9. Chr: Wrong side, wrong entrance into the atmosphere.
10. T: Yes, how can that [go] wrong?
11. Chr: When it eh, when it, like, plunges into the atmosphere in a wrong curve...
12. Ll: It burns.
13. Chr: …then it burns.
14. T: Yes, yes, so that can…
15. Chr: It stays longer in the atmosphere and then, it ‘ll remain longer hot.
16. T: Yes, yes, that could be. What could be as well? (2s) I thought, it can have encountered something along the way. […]

[…]

17. T: […] All right, where we are going to think about for a moment is all those things that fly in space. All those fragments. Why would it be important to know how they fly?

When compared to the scenario several remarks can be made concerning the content of this introduction. According to the scenario the teacher should firstly introduce the topic of mechanics as ‘explanation of motion’, without addressing the content of explaining, but emphasising its theoretical importance. Secondly he should introduce the example of an asteroid moving towards earth, as an illustration of both the importance of being able to explain and therefore to predict motion and that explaining motions entails quite a lot.

This does not quite happen in (1). On the basis of the teacher’s questions moreover, a student seems to consider the topic rather unproblematic (2). The teacher’s follow-up question in (3) ‘Yes, but how can something go on’ cannot yet be a real question for students. The long account in (3) is rather confusing. What can students understand from ‘the things we have altered and adapted a bit’, or of the reason given for studying two theories, for example? The teacher then does give some outlook on what is going to happen in the course (4), namely thinking of some kind of theory and then checking if it works in practice using the motions in the solar system. According to the scenario, the example of an asteroid moving towards earth should be addressed. This does not quite happen from (5) onwards. The teacher chose another example, which is perfectly alright as long as it is equally, or even more, clear in making the intended point that explaining or predicting motion can be desirable and is not an easy job. However, this was not the case. The question the teacher poses is why it would be important to know the motion of rock fragments (17). The example of the space shuttle (5, 6) was at the time current, but did not emphasise prediction or explanation of motion.

In the ‘main question and answer phase’ students were expected to come up with some answers that would indicate that they knew what the topic was about (explaining/predicting motions), that this had some importance and that a lot is needed for this. Students responded to the questions roughly as expected. Written answers that were given in response to what other motions are important to be able to predict or explain (question 1) were for instance typhoons, earthquakes, day and night, collapsing of demolished buildings and the tides. These things, which can be described as 'major contrasts to rest', apparently came up when students thought about 'motion'.

What the topic was about was not immediately clear, since there was some confusion about the meaning of 'motion'. Take for example the following two fragments:

1. Jol: What kind of motions do they mean?
2. Chr: Well, if they indeed reach the earth.
3. Jol: Hm. (50s)

4. Chr: What does this mean: can you think of other motions?
5. T: Yes.
6. Chr: Is it not simply assertions?
7. T: No motions. Motions. Things that move. Look, those asteroids move and sometimes they encounter the earth and sometimes not. Yes? Well, that is an example. So it is important to know whether it will encounter the earth...

Jolien expressed uncertainty about the kind of motions the question refers to (1) and is not convinced by Christiaan's response (2). Christiaan himself was equally uncertain, for some moments later he asked the teacher what is meant by motions (4) and even suggested that something else could be meant, namely 'assertion' (6) (in Dutch the words for motion 'beweging' and assertion 'bewering' are quite similar). The teacher's response that what is meant by motions is 'things that move' seemed to satisfy these students.

The spectrum of responses to the question what would be needed for such a prediction or explanation of motion and what could be meant by (and needed for) 'calculating' motion (question 2) included (the number of students that wrote a particular item down is written in parentheses behind the item): Measuring equipment (2), investigation of earlier asteroids that had hit the earth (3), simulations (2), the response of Merlijn (see below) or the response of Mick (see below). What is calculated is the trajectory (7) and the speed (4), for which is needed things as (initial) speed (2), changes in direction (1), the size of the asteroid (1), data from motion of other asteroids (5), data, rules or formulas (3), the manner in which the asteroid moves (1), influence of other asteroids (1), air pressure (1).

From the questions to the teacher and me that were posed in the lesson follows that students were not content with and certain about the given answers. From these answers can become clear that what is predicted is the trajectory of the asteroid and its speed and that it somehow includes calculations for which several useful intuitions surfaced, including the kind of data and required rules or formulas.

The purpose of the evaluation of these answers was to make sure that the intended conclusions, that precisely predicting or explaining motion is both important and difficult, surface by highlighting such answers that already contained them or adding to answers that did not. This was not done by the teacher, although sufficient student input was available. Take for example the response of Merlijn to question 2:

1. T: Yes. How does the predicting or explaining work?
2. Mer: Well, I've got the explaining with mathematics or physics. Then you calculate it. And by investigating.
3. T: Yes.
4. Mer: And prediction: the speed, starting point, magnitude of the thing, where it goes to and the larger the object is, the more difficult it will change its speed direction or something like that.
5. T: Yes, so you say like, a real motion of [this] thing eh. That is the speed, there it is. And with mathematics, physics you simply mean calculating with formulas, put things in and get things out.

As expected, Merlijn's answer is pretty vague, but does indicate that explaining involves quite a lot including mathematics, physics, investigation (2) and knowledge of specific conditions like speed and starting point (4) in which already a first regularity relating some condition (in this case the size of the moving object) to its change in direction or speed is found (4). At this stage it would be premature to address this last remark. Instead of emphasising the conclusion that explaining involves quite a lot and adding to this that it is therefore quite difficult and challenging, the teacher repeats her answer and adds to this his reading of what she meant by 'mathematics and physics' (5).

The point that predicting motions can be important would have needed more drawing out by the teacher, take for example Mick's response to the first question:

1. T: Right, do explain. Question 1 if you please.
2. Mic: [Reads aloud] Rotation of the earth, the answer is, people would like to know when it will be day and night. And eh, for example the seasons. On one side the sun is standing more to the north of the earth.
3. T: Yes.
4. Mic: Asteroid move towards earth. They like to know whether the earth is hit. Because people like to be prepared. And not be made afraid unnecessarily.
5. T: Yes. (many?) examples. And you?

The examples Mick mentions are at face value not very useful for illustrating the main points. Predicting day and night or seasons (2) is not particularly hard to do and it is not clear why it would be important. However, follow up questions might have led to the main points, for instance 'what is being predicted?', 'is this really predicting?', 'which motions are we talking about?' and 'why do you consider these important?'. (Mick does indicate why prediction of asteroids would be important, namely people like to be prepared (4)). With questions like these the point that predicting motion could be important may surface.

According to the scenario the teacher also should initiate a discussion (related to question 2) about what might be needed for *calculation*-based explanations or predictions. This did not happen, although the written answers to question 2 showed promising leads, like the mentioned data, formula or rules.

So some opportunities for explicating or drawing out the intended conclusions were lost. Unfortunately the raised uncertainty about how explaining works has not been made explicit as such by the teacher, thereby giving a sense of direction, e.g. by saying that these kind of questions will be the topic of study in this course.

Answering the analysis questions

1. It has to be pretty vague at this stage what is meant by explaining motions and also why that may be important, since both the introduction and evaluation did not focus on this point to the extent that was intended and possible. Students did get some impression in the introduction and did mention (implicit) reasons for the importance of what they thought to be the topic. In all they did seem willing enough to continue.

2. Explaining is not considered to be a simple matter, since students are aware that it involves numerous things. However, its difficulty and that it involves calculations has not yet been sufficiently emphasised and it is uncertain whether this is recognised.

Suggestions for improvement

There are no indications that the design needs to be changed, except for a reformulation of question 1. Question 1 did not focus on motions. A better formulation of this question would therefore be:

> Question 1: Of which other things would it be important to know how they continue their motion?

4.2. Episode 1.2: Triggering the general explanatory scheme

What happened?

It was intended that in the introduction a transition should be made from *why* one would study explaining motions to *how* this explaining might work. The teacher did not do this.

According to the scenario, in the main question and answer phase the general explanatory scheme is gradually triggered as a useful way of looking at some given examples of explanations. The examples concerned three explanations, attributed to Kees, Els and Jostein, of the dissolution of sugar in tea, which were expected to clearly illustrate the general explanatory scheme. The related questions of what these three people (dis)agree on (question 3) and what they explain and how (question 4) were discussed in groups of 3 or 4 students. The common written answer to question 3 was that Kees, Els and Jostein agreed on the fact that sugar dissolves and disagreed on the speed in which it dissolves. This was unexpected. I expected that students would have had some notion that Jostein and Els not necessarily disagreed, but that they would have found it difficult to express this notion. In response to question 4 students wrote that Kees, Els and Jostein explained in different ways that sugar dissolves. As an answer to how they do that the statements of Kees, Els or Jostein were repeated. Apparently this was found to be difficult to express, as was expected.

Whether the general explanatory scheme can be triggered quite naturally depends on whether question 3 and 4 triggered statements in which the teacher could recognise elements of the explanatory scheme. For this the written answers did not suffice and I had to look into the recorded discussions to see which statements were triggered by question 3 and 4. The relevant audio fragments were found by selecting the sections where students discussed question 3 and 4 and searching for keywords indicating talk about causality like ‘because’, ‘hence’, ‘why’, ‘so’, ‘for’. I found three relevant fragments in the two groups. For each group I will first display the fragments and then discuss them.

Group 1, first fragment

1. Nic: So, it is right that those, those Kees and Jostein say, no, no, Kees and…
2. Ros: Els
3. Nic: …Els, yes, say that it therefore, that it slowly dissolves. And how that is reached. And Jostein says that it dissolves quickly and he also says what the cause of that is.
4. Ros: But what do they *explain*?
5. Mic: But does Els say that it quickly dissolves? Or doesn’t quickly dissolve, but of why.
6. Ros: ‘It dissolves quite fast.’
7. Mic: No, Els. You should have stirred. But then she does not explain why it does not dissolve quickly.
8. Ros: Yes, she does, because they do not stir, it does not dissolve quickly, according to her.

Group 1, second fragment

9. Ros: Kees just says sugar is dissolvable. (2s) That is his explanation.
10. Nic/Ais?: Ok.
11. Ros: Isn’t it?
12. Mic: Well also. Just say it slowly falls apart, it is dissolvable.
13. Ros: But that is no explanation. That is just something he sees. You have to say why he says that it falls apart, in my opinion.
14. Nic: Yes, ok.
15. Mic: Just say it slowly falls apart. It is dissolvable.
16. Nic: Jostein says that the tea is very hot, but that doesn’t make sense either.
17. Mic: No, but he explains it in that way.
18. Ros: Yes, he does, but it is the warmer that thing …
19. Nic: Yes, that is so, ok.
20. Ros: … the tea is.
21. Mic: Jostein: the tea is hot.
22. Ros: And there hav…
23. Nic: Els.
24. Ais?: Sugar.
25. Ros: Shouldn’t there be, shouldn’t we add ‘and how quickly it goes’
26. Nic: Yes.
27. Mic: Yes?
28. Nic: And Els is eh. If you want sugar to dissolve you have to stir.
29. Ros: Els.
30. Nic: No, if you no.
31. Ros: Can you sooner, or you haven’t stirred. (4s)

32. Nic: What, you haven't what?
33. Ros: You haven't stirred. There was no stirring. That's why it goes more slowly.

Discussion of these fragments: In their descriptions of how explaining works basic elements of the explanatory scheme can be recognised. Nic formulates this as 'and how that is reached' (3) and 'what the cause of that is' (3). This points in the direction of a causal factor or a regularity (which is almost the same thing, see chapter 3 section 2.1). When Mic objects that Els does not answer the question why it doesn't dissolve fast (5, 7), Ros counters by mentioning a causal factor: 'Yes, she does, because they do not stir, it does not dissolve quickly, according to her' (8). When Nic seems to protest that Jostein also doesn't give an explanation (16), Ros counters again by giving a causal factor: 'Yes, he does, but it is the warmer that thing, the tea is…' (18, 20). In both cases Mic and Nic seem to accept Ros's argumentation. They do not continue objecting and they actively add a causal factor: Mic mentions in relation to Jostein the factor 'hot' (21) and Nic in relation to Els the regularity 'If you want sugar to dissolve you have to stir' (28). An element of the explanatory scheme that I only implicitly recognise is the element of comparison of two situations. It was not said, for instance, 'if the tea would have been colder, it would not have dissolved as fast' or 'if one had stirred, it would have dissolved faster'. Ros is getting close when she uses a comparative degree in her half finished regularity: 'Yes, he does, but it is the warmer that thing, the tea is…' (18, 20). And when she corrects Nic's regularity: 'You haven't stirred. There was no stirring. That's why it goes more slowly' (33)

Group 2

1. Mer: How do they explain it? By looking, isn't it. Different ways.
2. Jol: The one says you have to stir.
3. Mer: The one says: it slowly falls apart.
4. Car: Yes, the other says that it is very hot.
5. Chr: They just think (…), they think about the properties of tea and sugar. And then they think of yes the one thinks that really hot sugar falls apart and the other (says) because you stir. Does fall apart.
6. Mer: Oh yes.
7. Car?: Yes.
8. Jol?: (…)
9. Mer: I don't know too. I think about the properties of tea and sugar.
10. Car?: Because tea is hot.
11. Mer: Yes
12. Car?: And sugar dissolves.

Discussion of this fragment: Also in the discussion of this group elements of the explanatory scheme can be recognised. Jolien and Carlijn start by mentioning 'stirring' (2) and 'very hot' (4), that Christiaan tries to characterise more generally as 'properties' (5). At least Christiaan and Carlijn seem to be using these as causal factors: 'because you stir' (5) and 'because tea is hot' (10) respectively. The fact that they only talk about Jostein and Els suggests that the students in group 2 implicitly question whether Kees explains anything at all. I do not recognise explicit mentioning of a regularity, neither the comparison of two situations as elements of the explanatory scheme. (They are implicitly contained in the idea of causal factors).

So question 4 did seem to do the trick in triggering talk in which elements of the explanatory scheme can be recognised (the missing explanatory scheme element of a comparison is taken care of in later questions, so that need not trouble us here). No elements were found in connection with question 3, which suggests that it may be revised or skipped altogether.

These fragments also illustrate some other features of the group discussions of these assignments, namely that students participated enthusiastically in their group discussions, that the assignments seemed to be understood, given the type of answers that were given (all related to the questions) and that the discussions were about what was asked, and that the focus of the attention lay on explaining instead of the explained phenomenon.

According to the scenario, in the evaluation phase the general explanatory scheme is made explicit in connection to what the students had put forward in the discussed examples of explanations, which is facilitated by using a figure depicting the explanation of Els (see chapter 5, figure 2). The teacher did not use this figure. Sufficient elements in students' answers could have been pointed out, but were not. Among these elements the notion of comparison of two situations did become clear, but it was introduced in the context of an experiment instead of emphasising that the *explanations* that were given can be understood in that light. The element 'regularity' was not clear at first but was later clarified after some questions from students.

There is an indication that a proper evaluation would have led to more understanding. I answered a question from Rosa concerning the filling in of the mentioned figure (when she encountered it in the students booklet), which made the explanatory scheme explicit in the intended way. This seemed to solve Rosa's problem, which indicates that the intended evaluation can in fact be understood.

Answering the analysis questions

3. Since the answers to questions 3 and 4 and especially the related discussions showed considerable participation and interest (for the right theoretical reasons) and the focus lay on explanations instead of explained phenomena students can be said to be intellectually challenged by how explanations work, although it is hard to say whether the goal of finding a structure in explanations has become clear.

4. The general explanatory scheme can be triggered quite naturally in this way. There are plenty of elements of the scheme that can be recognised and pointed out in students' responses to the questions. (To what extent students would recognise the scheme as underlying their own explanations and consider looking at their explanations in this particular way as quite obvious or even familiar when it would have been made explicit is difficult to say at this stage.)

Suggestions for improvement

Question 3 might be incorporated in question 4. Question 3 leads up to question 4, but the same function of 'leading up to' can be more efficiently taken care of by reformulating question 4 as (after the explanations of Kees, Els and Jostein)

Question 4. Compare your answers and try to reach agreement on:

- *Do Kees, Els and Jostein explain the same thing? What do they actually explain?*
- *How do they do that?*

4.3. Episode 1.3: Making use of the general explanatory scheme

What happened?

The introduction was read by the students, as was intended. According to the scenario, in the main question and answer phase students were to apply the explanatory scheme to the explanation of Jostein (question 7) and Kees (question 8). They were expected to be able to add something to the drawings, point out the relevant difference between the cases, mention a few factors which have to be the same in both cases and finally formulate a regularity. They were then expected to answer more sharply the question why Els and Jostein not necessarily have to disagree (question 9), which is a repetition of question 3.

The students were able to answer questions 7 and 8 in the expected way. Most came up with the regularities 'when you stir, it goes faster' related to the explanation of Els and 'when the tea is hotter, the sugar dissolves faster' related to the explanation of Jostein. Mentioned factors that need to remain the same were temperature (in the case of Els), amount of tea, size of the cup, same sugar and same tea. In response to question 9 the students stuck to their opinion that Jostein and Els agreed on the fact that sugar dissolves in tea and disagreed on the speed in which sugar dissolves. Some suspicion that Jostein and Els might have agreed on the speed of dissolution was not found. Students' ability to answer these questions correctly at least indicates that they have some understanding of the used figures and elements of the explanatory scheme.

In the evaluation the teacher was meant to take stock of the answers and to point out the structure in them. Incomplete answers he should try to complete by further questioning. Students should then try to summarise the general explanatory scheme themselves in a couple of sentences or a story, or by using a picture (question 10). From these summaries of the scheme the teacher then should try to elicit the main elements of the general explanatory scheme using figure 3 from chapter 5. The teacher should end this episode by announcing an application of this general scheme to motion.

Question 7 - 9 were not exchanged. Question 10 was done as homework instead of the planned summary of exchanging the outcome of question 7 – 9. This question became much harder in this way, because students had to come up with a summarisation on their own. The original function of question 10, to indicate what they have understood of the general explanatory scheme, can therefore no longer be fulfilled. Students' answers did not and could not, given this deviation from the plan, express the general explanatory scheme in my meaning of the term, since the students were not told what that was. Their answers, on which they spent considerable thought and time, did express what they considered to be important in describing explanations systematically, it contained further examples of implicit use of the scheme whenever students explained or talked about explaining[3], but did not show the additional step of how they would have responded to an explication of their implicit use of the general explanatory scheme. A recurrent feature they mentioned was the (implicit) comparison of two situations, which is also one of the elements of the explanatory scheme. So although it was not explicitly mentioned as such, the examples and questions did at least instil this notion.

The homework (question 10) was 'discussed' the following lesson by merely[4] exchanging the various answers. No explication of the general explanatory scheme was attempted and no application of this scheme was announced. Whether the explanatory scheme had been recognised when it would have been explicated cannot be said, since it was not explicated. It might have been explicated in connection to students' input, since their input (answers to questions 7, 8 and to a lesser extent 9) was largely as expected. However, how they would have reacted to such an explication remains to be seen.

As was seen the execution of this episode deviated strongly from the plan. A number of factors contributed to this strong deviation. Some have a bearing on the design and are therefore important to discuss. The most notable factor is that the scenario does not state clearly how the explanatory scheme may be explicated based on students' responses to questions 7 – 9, although this is a crucial activity. Another factor explaining this deviation is the timing in lessons, that turned out different as planned. The lesson ended when students finished question 9, so it seemed straightforward to give question 10 as a homework assignment.

Answering the analysis questions

5. Indications for whether students understand the meaning of the elements of the general explanatory scheme were thought to be the kind of answers students give to questions 7, 8 and 9, whether the teacher is able to clearly explicate the elements in the evaluation phase and what kind of depiction of the general explanatory scheme students give themselves in response to question 10. The latter two sources can no longer be used in this way, given the mentioned deviations in the execution. The former source at

[3] Since several examples have already been pointed out in the description of what happened in episode 1.2, I think it is unnecessary to show instances of use of elements of the general explanatory scheme here. The point I tried to make then was that whenever people talk about explaining they necessarily use the general explanatory scheme, which can (not surprisingly) be pointed out. The question that remains is how this pointing out or explication of the scheme can be done in such a way that students recognise it and find it a natural or even familiar way of expressing what they do when they explain things. In order to answer this question students' reactions to attempts at explicating the scheme need to be investigated, for which question 9 was intended to provide data. Given the deviations in execution question 9 can not perform this function any more.

[4] Properly exchanging is already quite difficult. A teacher has to elicit answers from the students and therefore create a safe enough environment for this to happen. These answers need to be heard, understood and finally summarised in some meaningful way. In this case I mean with the slightly prerogative word 'merely' that the subsequent step of extracting from these answers the explanatory scheme did not take place.

least indicates that students have some understanding of the elements of the explanatory scheme.

6. An indication for whether the scheme would be helpful in clarifying explanations to students was thought to be whether students give a clearer answer to question 9 than to the similar question 3. My expectation was that students would have some notion of that Jostein and Els not necessarily disagree, not even about the speed of dissolving and that they would find this notion difficult to express. The explanatory scheme may be useful in expressing this notion of not disagreeing, for instance in terms of differing situations with which the explained situation is compared. Without this experienced difficulty in expression the scheme cannot provide this clarifying function. My expectation turned out to be false. Comparing answers to question 9 with question 3 does therefore not give any indication whether the explanatory scheme is helpful in clarifying explanations to students, unfortunately.

Suggestions for improvement

As was mentioned before the scenario lacks clear suggestions for the teacher how to explicate the scheme. What might those suggestions entail? After question 9 the teacher should point out the following elements in students' answers: the comparison of two situations, the factor in which these two situations differ, other factors that are the same and the regularity. The regularity is intimately tied up with the factor in which the situations differ or the 'cause'. The relation between the two is that the cause that we identify can only be a proper cause when we can call upon a plausible regularity which expresses that when the cause is present the result will follow. (And the result is the situation or event one wants to explain.) After explicating these elements the teacher should say that these can be found to underlie all (causal) explanations and that this underlying structure is called the (general) explanatory scheme. Students then can continue with question 10 after which the original scenario can be followed.

The example of an explanation of sugar dissolving in tea did not provide a reason for using the explanatory scheme in allowing to express clearly why the different explanations not necessarily disagree. This is a pity and might be remedied in two separate ways. The first way is finding an example that does perform this function as well as the other functions of the tea example like triggering all elements of the explanatory scheme. The second way is retaining the tea example and find another way of showing the scheme's use. One can even consider not remedying it. The scheme's main use is theoretical, which is emphasised throughout the course. Its practical use in clarifying the expected suspicion of students that Els and Jostein not necessarily disagree can be considered a bonus. Not cashing in on the bonus is not that important. In a revised scenario some choice in this matter should have to be made.

Concluding remarks

Since the general explanatory scheme has not become explicit the parallel between the general explanatory scheme and the explanatory scheme for motion (that will be introduced in the next episode) cannot be understood, for it was precisely in making explicit this parallel that the teacher was deemed necessary. This was later confirmed in interviews conducted at the end of the introductory course concerning the recognition (if any) of the main line of the course. Only Merlijn and to a slight extent Carlijn and Nicole indicated that they had recognised the link between general scheme and scheme for motion. Others failed to see this link. That the element of comparison of two situations was recognised as an important element in explaining by the students, suggests that at least this element might have been easily recognised as linking both schemes. This is an important point because it was precisely the difficulty in getting across the importance of comparison when starting with the explanatory scheme for motion in the first trial that triggered the idea of using the general explanatory scheme as a stepping-stone. This, I think, is an indication that using this particular stepping-stone might be a good idea.

4.4. Episode 1.4: Triggering the explanatory scheme for motion

What happened?

According to the scenario, in the introduction the teacher should make the transition to the explanation of motions by pointing out that since explaining motions is a particular case of explaining in general the general explanatory scheme may give ideas of how to look for the structure in explaining motions. The teacher said the following:

1. T : But we are going to make a theory of the moving of the bicycle rider. Not because that is so terribly interesting. And we do not look at riding with no hands and other things, just very simple.
2. T: And it concerns rather a kind of variation of question 10, of how to exactly put up a theory. Well, later we will apply this to heavenly bodies.
3. T: So it does not really concern that bicycle rider, it concerns, just for now that bicycle rider, but it concerns how we make a theory.
4. T: Which steps does it contain. Yes. And that is on the one hand things that you know, that you have observed. And on the other hand you try to mould them into a particular shape.
5. T: And that shape into which we are moulding it. That shape keeps returning. Yes? All right, then I will divide you into funny little groups that will stay the same all lesson. Namely, groups of two.

The connection that is made between the general explanatory scheme and the explanatory scheme for motion consist of calling what we are about to do a variation of question 10 (2) and a recurrent ‘shape’ (5) in which the things that we know or have perceived are moulded or organised (4). Furthermore the point is emphasised that not the particular example is important (1, 3), but the making of a theory (1, 2, 3) and that this will be applied to heavenly bodies (2). Since the general explanatory scheme had not been made explicit in the previous episode, it is more difficult to make the transition here to motion. On the other hand, this could have been an opportunity to try to repair this earlier omission.

In the main question and answer phase a number of questions, concerning easy examples in which two different motions of a bicycle rider are compared, should guide students in filling in elements of figures depicting explanations of motions. These question were indeed answered as expected. At first, students were a bit uncertain whether the given answers were in accordance with the meaning of the questions, given statements like ‘is that all’ or ‘have I done this correctly’. The given help by the teacher and me consisted mainly of guiding questions, without giving much away. The right elements of the explanatory scheme were put in the right places. One group of students was even able to do it correctly without reading the guiding questions 10, 11 and 12. Apparently this way of depicting explanations seems quite straightforward to students. The attention remained focussed on explaining instead of the explained phenomenon.

In the evaluation the teacher should take stock of the answers and point out the explanatory scheme for motion in them. The first formulation of the explanatory scheme for motion should then be extended to include all influences. ‘Influence’ should be distinguished from ‘influence affecting factor’. The teacher should then conclude that we have arrived at an explanatory scheme for motion and announce that in the next episode its uses will be explored.

The evaluation consisted of a long monologue of the teacher (not presented here) in which all elements of the explanatory scheme for motion were mentioned. He also indicated that a choice for a situation without the relevant causes or influences (the influence free motion in case of the explanatory scheme for motion) has got implications for the other elements of the explanatory scheme and that we were not interested in particular examples, but in a general ‘theory’. (It was recommended earlier in the scenario to repeat the latter point several times. To do so here is a good choice.) Here the teacher mentioned that the examples of the bicycle rider and the sugar dissolving in tea could both be depicted with the same abstract figure (figure 3 from chapter 5), which was intended for the previous episode, but used here instead. This was all done without using student input.

The teacher then started to continue with the next episode, skipping the more general notion of influence, the related question 16, the distinction between influence and influence affecting factors, and the preparation for the next episode, at which point I addressed the distinction between influence and influence affecting factors myself, of which only Jolien made notes. Others seemed not to understand this distinction. Aisha, for example, clearly did not get this point as can be seen from the following fragment:

1. T: And what is working, eh, which influences are working? What is the influence with Kepler?
2. Ais: Well, distance or something?
3. T: No, the distance in not the infl, the distance does not do anything. Who does something? Who does, who influences it?
4. Ais: The sun (…)
5. T : The sun. So, and what about the sun? The ...?
6. Ais: The motion of the sun. Eh, the rotation speed.

First Aisha calls the Keplerian influence the distance, which is an influence affecting factor (2). The teacher corrects this in (3) and asks about the influencer, which Aisha correctly identifies as being the sun. The teacher then hints at a further answer, probably intending something like ‘the drag of the sun’. Aisha, however, gives another influence affecting factor, rotation speed (6), which is not corrected. Although this is only one example, which I selected for being very explicit, more confusions of this kind arose with other students.

Answering the analysis questions

7. Students are able to point out most elements of the explanatory scheme for motion, for they gave the expected answers to questions 10 through 14. The distinction between influence and factor, however, did not become clear.

8. Given the relative ease at which students responded to the questions, the explanatory scheme for motions could quite easily be triggered. The teacher also explicated it more or less as intended, but it is at this stage difficult to say whether students find the scheme naturally underlying explanations of motion, since their answers to the questions were not explicitly used in explicating the scheme and their reactions to the explication that took place were minimal.

Suggestions for improvement

There are no indications that this episode could not perform its function of making students realise that the explanatory scheme for motion (as a special case of the general explanatory scheme) can be recognised in explanations of motion. However, there is certainly room for improvement, since the function of the distinction between influence and influence affecting factors cannot be clear at this stage. The same can be said of the distinction 'regularity' and 'relation influence – motion' (see also Figure 4 from chapter 5). The teacher explained that this distinction is useful for understanding motion, which the students are certainly willing to believe, but cannot understand. The scenario does not give additional answers and is therefore lacking in this respect. I will return to this point in the next section.

4.5. Episode 1.5: Making use of the explanatory scheme for motion

What happened?

According to the scenario, the teacher should introduce this episode by pointing out that one use of the explanatory scheme for motion may lie in solving the initial asteroid problem (and implicitly therefore also in explaining and predicting any motion). This did not happen.

In the main question and answer phase students should identify those elements that are needed to solve the asteroid problem by answering the question, with the help of figure 5 from chapter 5, what things one would have to know to be able to give an explanation, given the explanatory scheme for motion. I will here give a complete set of what students wrote down in response to that question. The mentioned figure is displayed again in Figure 1, only this time with numbered cells. These numbers will be used to indicate in which cells students wrote down their statements.

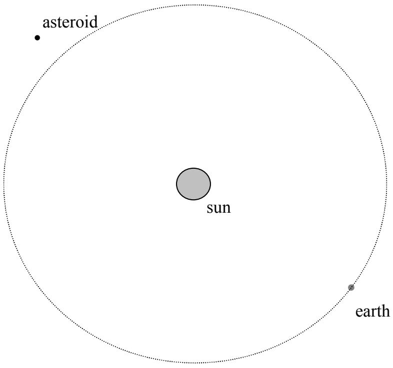
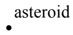
Motion of the asteroid: … (1)	**Influence free motion** of the asteroid:… (2)
 (3)	 (4)
Working is: - … - … (5)	No influence is working on the asteroid. (6)
Regularities: …. ….(7)	
Relation influence - motion: …(8)	

Figure 1: Asteroid towards earth

This is what they wrote down:

Mick: (5) the earth attracts the asteroid just like a truck that passes by very fast

Christiaan: (5) attraction; a force forward/backward

(7) the closer to the sun, the larger the attraction on the asteroid, the larger the force forward/backward.

(8) the more the asteroid is influenced by forces the more and larger the motion

Aisha: (5) collision with object in space; speed at which it approaches earth

(7) when it for example collides with an object in space then the trajectory in which it comes can deviate

(8) when it comes in a straight trajectory to earth then it is faster than [not finished]

Nicole: (5) influence of other asteroids

Jolien: (5) steering of the asteroid; the asteroid also rotates around the sun

(7) without influence the asteroid remains approximately at the same place

Carlijn: (5) speed, trajectory/direction; attraction of the sun

(7) when the attraction is large, the asteroid abandons its trajectory

Merlijn: (5) sun; earth

(7) when the asteroid is close to earth, then you can determine where the asteroid is.

(8) The closer the earth is to the asteroid, the better you can see it.

Students were expected to be able to completely fill in this figure, but what they wrote down was incomplete. They found answering this question difficult and were unsure about their answers. Take for example Merlijn and Jolien:

1. Mer: When the asteroid is close to earth, then you can determine where the asteroid is.
2. I: Yes yes. For then you can see it or something like that, what do you mean?
3. Mer: Yes, look when the earth is turning then (...)
4. I: Yes.
5. Mer: Well, then one can probably see whether it is there, kind of.
6. I: Hm hm
7. Mer: I didn't really know. I tried something.

Merlijn indicated as a regularity that when the asteroid is close to earth, you can determine where the asteroid is (1), but indicates that this answer was more of a guess (7).

1. I: Do you find it difficult?
2. Jol: Yes.
3. I: What is difficult?
4. Jol: (4s) Just difficult.
5. I: Hm. But you did write something down.
6. Jol: Yes, but I don't know whether that is true.

Jolien found the question difficult (2), cannot even express what is difficult about it (4) and also indicates uncertainty about her answer (6).

In the evaluation the given answers should be discussed where the teacher should emphasise *that* the elements of the explanatory scheme are needed for an explanation and that we do not yet know *what* these elements look like precisely. The explanatory scheme for motion, therefore, is useful in the sense that it provides for a handle on the problem by pointing out the elements student still need to learn more about in subsequent episodes. This evaluation did not take place in this lesson (lesson 2) nor in the next. Although it became a point of attention for lesson 3, it was somehow overlooked.

Answering the analysis questions

9. Given the deviant way in which this episode was executed it is not surprising that students cannot be said to have understood that in order to explain the motion of the asteroid they would have to know how the asteroid would move without any influences, which influences were operating (and where they came from), and how these influences caused deviations from the influence free motion. They answered the main question

incompletely, so could not think of the answers themselves, which was unexpected from the point of view of the scenario, but given the earlier deviations and shortcomings is not that surprising any more. Their answers were not corrected and completed, because in the evaluation the explanatory scheme was not explicated at all, let alone clearly, which would have required substantial input from the teacher. Students could also not be expected to have realised which elements of the explanatory scheme for motion are still unknown, because they were not identified. Finally the agenda for the following lessons was not set at all, let alone clearly.

Suggestions for improvement

One point concerning the design of this episode is that the regularity has been distinguished from the relation influence – motion (see also Figure 1), but no reason was given for this. The reason I as a designer had for this distinction is that it prepared the ground for later introduction of influence laws as specification of the regularity and the rule deviation=influence/laziness as specification for the relation influence – motion. Students could of course not see this reason and should be provided one that they can understand and appreciate. A revision of the design should address this issue.

A similar issue involves the distinction influence – factor, where influence will later turn out to be force and factor a variable in a force law. Here the scenario does give an explanation of the difference, but no reason why this is important.

Concluding remark about the design of this episode

At face value the deviations in execution make it very difficult to draw some meaningful conclusions regarding the design of this episode. However, the answers students gave in response to the main question do give some concrete leads as to how the teacher might have responded. It is my claim that the test of this episode gives additional empirical information in support of the design besides the theoretical arguments already given in the scenario. To back this claim I will give a possible response to the answers students wrote down in which the goal of the episode may be reached. In this way, by 'reconstructing'[5] a teacher response I intend to illustrate that a proper response had been possible, given the student input, and might have resulted in the desired outcome of this episode.

The teacher could have responded in the following way, after the answers to the episode's main question were read aloud (or exchanged otherwise):

> *Although none of you have given a complete answer, you do mention a lot of elements. The most of what I hear/read is about what is working. The influences working on the asteroid. Mick mentions an attraction from the earth, Christiaan also an attraction, Carlijn an attraction from the sun, Christiaan also mentioned a force forward/backward, Aisha collisions with other objects in space and Nicole the influences of other asteroids. Nicole, do you think about collisions or maybe also attractions or something else? Merlijn, what do you mean by sun and earth?*

[5] This way of reconstructing a teacher response resembles the reconstruction method of Kortland, but is less strict in the sense that it does not follow all the guidelines he established.

I would expect that Merlijn would join the mentioned attraction by sun and earth, since she indicated at another instance that this answer was a guess.

Maybe you disagree whether some influence is or is not there, but we can agree on that when some influence is working, you have to know how it is working if you want to predict the trajectory of the asteroid, don't you?

The reason that influences matter is that they change the trajectory of the asteroid. Without influences the asteroid will move in some manner and with influences in some different manner. Comparing these two ways of moving leads to identifying influences. This is similar to the comparison of two situations that we saw in the explanations of sugar dissolving in tea. What counted as a factor accounting for the difference between slowly and quickly dissolving, e.g. the temperature, depended on what situation one had chosen as a reference. The same here: what counts as an influence depends on what motion one has chosen as a reference, that is what influence free motion.

What motion will the asteroid have when there are no influences working, do you think? There are several possibilities. Jolien mentioned that according to her the asteroid would remain in its place. Christiaan did not mention this, but implicitly he did. Christiaan said that there has to be a force forward/backward. Why do you think so, Christiaan?

I expect an answer like: otherwise it would not move in the direction it is moving, it would move straight towards earth because of the attraction of the earth.

Ok, so when we try to indicate which influences have to be working, we also say something about what would happen when these influences were absent. That is to say, we make an assumption for the influence free motion, here on the right side of the figure (pointing towards Figure 1 cell 2).

An influence has to come from somewhere. There has to be an influencer. You also mention something concerning this point. The attraction comes from the earth (Mick) or from the sun (Christiaan, Carlijn). Christiaan, where would the force forward/backward come from?

He might have some idea on the topic.

Or the influence comes from collisions with objects in space (Aisha) or from other asteroids (Nicole). In that case it is clear where the influence is coming from and what the influencer is. The magnitude of an influence depends on where it is coming from. It depends on the influencer. This can be expressed by a regularity like Christiaan did. Look here in the figure (points towards Figure 1 cell 7). He said, 'the closer to the sun, the larger the attraction on the asteroid, [and] the larger the force forward/backward'. The other 'regularities' by Aisha, Carlijn and Merlijn that were mentioned do not express the magnitude of the influence, which is the meaning of regularity used here.

Apart from the distance Christiaan mentioned, what could also determine the magnitude of his attraction by the earth or sun?

I expect someone to come up with the notion of size or mass, otherwise the teacher may put this forward without much resistance.

> *All right, suppose that we know now which influences are working (points to figure cell 5) and we have (therefore) also an assumption for the influence free motion (points to figure cell 2). And we also know the magnitude of these influences, because we know where they come from (points to figure cell 3 and 7). In order to predict the motion we would have to know how all those influences together cause a deviation from the influence free motion. What is the effect of the influences on that motion? (Points to figure cell 8). That is something we also need to know.*

Here the teacher might give an easy example illustrating that influence needs to be transformed into deviation (from the influence free motion).

In this way a teacher might have reacted to the written answers to the episode's main question. I expect that students would find most of this understandable and would be able to recognise their answers in my reading of them. The more difficult parts were explicating the implicit assumption of an influence free motion that is coupled to the identification of influences and the elements regularity and relation influence – motion. The relation influence – motion is now introduced as an element we need to know more about (in order to be able to predict the motion), without connecting it to student input.

To end this discussion of a hypothetical teacher response I like to note that this episode is a crucial activity in which all previous activities culminate in a structure which sets the agenda for the subsequent activities. It is therefore a pity that this was not executed properly. In theory this can be done clearly and using student input, as I tried to illustrate with my hypothetical teacher response above. In practice this proved very difficult given the kind of preparation that was offered.

4.6. Conclusion main theme 1

Before drawing some conclusions concerning theme 1 as a whole I will summarise the answers to the analysis questions related to the various episodes in the following table, see Table 1.

The ideas for triggering and explicating both the general explanatory scheme and the explanatory scheme for motion might work in the designed way, but they are (too) difficult to execute for the teacher without sufficient training. The important topic of teacher preparation, including the specific difficulties related to a problem posing design and ideas for approaching it were discussed in section 3 and will be further addressed in chapter 7. The test does not give further empirical information as to whether the schemes will be recognised or considered familiar or at least not considered strange after explication. This question remains unanswered here and will require further research for answering it in the future.

The asteroid problem might perform its intended function, when properly used. Using the general explanatory scheme as stepping-stone simplifies the introduction of the notion of comparing situations in explaining, but has not been used explicitly enough in the transition to explaining motion.

<table>
<tr><td colspan="3">Main theme 1: The why and how of explaining motions.</td></tr>
<tr><td colspan="3">Function of main theme: It addresses the questions of why study the topic of explaining motions and how are motions explained. This should result in the notion that this is an important and interesting theme worth knowing more about and the feeling that it is a theoretical challenge to explain motions by means of an as yet unknown specification of the underlying scheme (theoretical orientation).</td></tr>
<tr><td>Episode</td><td>Analysis Questions</td><td>Answers</td></tr>
<tr><td>1.1 Introduction to the topic of mechanics</td><td>1. What indication can be found that explaining or predicting motions can be desirable?

2. What indications can be found that students consider explaining not as a simple matter?</td><td>What is meant by explaining motions and also why that may be important is still vague. Students did get some impression in the introduction and did mention (implicit) reasons for the importance of what they thought to be the subject and seemed willing enough to engage in the subject.
Students are aware that it involves numerous things. It is uncertain if its difficulty and that it involves calculations has been recognised.</td></tr>
<tr><td>1.2 Triggering the general explanatory scheme</td><td>3. Are students intellectually challenged by how explanations work?

4. Can the general explanatory scheme be triggered quite naturally?</td><td>Yes. The answers to questions 3 and 4 and especially the related discussions showed considerable participation and interest and the focus lay on explanations instead of explained phenomena.
Yes. There are plenty of elements of the scheme that can be recognised and pointed out in students' responses to the questions.</td></tr>
<tr><td>1.3 Making use of the general explanatory scheme</td><td>5. Do the students understand the meaning of the elements of the general explanatory scheme?
6. Is the scheme helpful in clarifying explanations to students?</td><td>Students have at least some understanding of the used figures and elements of the scheme.
Hard to say.</td></tr>
<tr><td>1.4 Triggering the explanatory scheme for motion</td><td>7. Are students able to point out the elements of the explanatory scheme?

8. Can the explanatory scheme be evoked naturally?</td><td>Yes, most elements. The distinction between influence and factor did not become clear.
Yes, given the relative ease at which students responded to the questions. It is difficult to say whether students find the scheme naturally underlying explanations of motion.</td></tr>
<tr><td>1.5 Making use of the explanatory scheme for motion</td><td>9. Do students understand that in order to explain the motion of the asteroid, they would have to know how the asteroid would move without any influences, which influences are operating (and where they come from), and how these influences cause deviations from the influence free motion?</td><td>No. They could not think of the answers themselves and their answers were not completed by teacher input.</td></tr>
</table>

Table 1: Summary of answers to analysis questions of main theme 1

Students did not see the explanatory scheme for motion as a special case of the general explanatory scheme. This was not pointed out and the general explanatory scheme as such was not established.

Students did not realise that for a complete explanation of motion further specification of the elements of the explanatory scheme would be necessary, but they might have realised it in a proper execution of the design, since their input allowed for a natural explication.

The students developed a theoretical orientation in the sense that they understood the goal of understanding explaining motions to be to arrive at some theory of motion, had some impression (however vague) of what such a theory might be, and were somewhat challenged by it.

Apart from the few scenario improvements that have been suggested in the course of section 4, this test did not provide empirical grounds for changing the design of main theme 1 in a major way. The encountered difficulties seemed to lay mainly in the execution and therefore the teacher preparation.

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

The following sections, section 5.1 through 5.5, concern the results related to the second main theme, extending students' knowledge. The same presentation format as was used in section 4 will be used here. Section 5.6 contains conclusions regarding the second main theme.

5.1. Episode 2.1: Transition to Kepler and Newton

What happened?

According to the scenario, the main thread that is followed is that all subsequent activities can be seen as further specifications of the explanatory scheme for motion. Students should be oriented towards the texts on Kepler and Newton as examples of such specifications of the explanatory scheme for motion. In the introduction (which took place at the end of lesson 2) the teacher gave a gripping human interest account of Kepler and Newton and pointed out that the following assignment (assignment 18) is about recognising the explanatory scheme in the texts. He did not mention oral presentations, which were mentioned in the student booklet. A kind of main thread was indicated, as can be seen in the following fragment from the introduction:

1. T: But everyone has to understand really well what the meaning of this is. I think you have lost the thread a bit.
2. Ll: Yes (…) [intonation suggests 'not really']
3. T: Shall we precisely explain the meaning once more, or shall we ask her to explain?
4. Nic?: Ask away.
5. T: You, explain very shortly what precisely the meaning is and what we are doing now.
6. Ais: (…)
7. T: Louder, louder.
8. Ais: (…) real earth and the earth (…) together (…).
9. T: Actually, I mean all lessons together.

10. Ais: Oh. Ehm then eh, then the general, say, so the explanatory (...) eh influence is of motion, sort of.
11. T: Yes. We are engaged with a general explanation, we apply it to motion, yes? So we divided [it] a little in parts. We got two people who had two different theories. Those two theories we are going to specify.
12. T: We are going to apply them later and next lesson we are going to look who of these two has got the best explanation and after that we are going to further detail it, like, filling in. Yes. The text says that the distance has an effect, but not how large that effect is.

I do not think that this makes the main thread much clearer to students, e.g. they cannot be expected to have a clear picture of what 'applying' and 'specifying' is (11). The last sentence does give some lead: The further detailing or filling in of 'it' (meaning the theory of Kepler and Newton respectively) means making it more precise, like estimating how large the effect of the distance on the influence is (12). He did not use Figure 5 from chapter 5 in this introduction.

In the main question and answer phase students should read two texts on Kepler and Newton in which their use of the explanatory scheme for motion should be easily recognisable. This is guided by the question whether they recognise the explanatory scheme in the texts, on which they should give an oral presentation. What happened was that most students read the texts as homework, but did not prepare an oral presentation, which was in agreement with the teacher's intentions, but not with the written assignment in the student booklet.

According to the scenario, in the evaluation the teacher should discus several presentations of students and try to elicit answers to the following questions:

1. What were the facts that Kepler and Newton tried to explain?
2. Do you recognise the general way of explaining? How was it applied by Kepler? How by Newton?
3. Why did Newton come up with assumptions for the influence law, which differed from those of Kepler, in particular with respect to the direction of the influence?

In connection to their responses the teacher should emphasise that Kepler and Newton explained the same phenomenon in the same structural manner, but differently in respect to the specifications of the elements of the scheme and address the difficult point of the connection between assumed influence free motion and identified influences. This should then result in the further filling in of the status diagram. Finally the teacher should state that some of the elements of the status diagram ought to be made more precise and that this will be the topic of the following couple of episodes.

In the evaluation the next lesson the students were not asked to give an oral presentation, but were asked factual questions like 'what is the influence free motion according to Kepler?' by the teacher. Their answers to these questions together with their filling in of the status diagram gave indications for the extent to which they recognised the elements of the scheme. Filled in status diagrams were correct, in the sense of answered as expected, except for the element of the influence free motion, which was either lacking or put at a different place. The model of Kepler appeared to be intuitively clear to students. Take for example the following response to a question of the teacher during the evaluation:

1. T: Well. Ehm, let's take another question. You'll know this one. What is with Kepler the influence free motion?
2. Mic: Well, eh, hm.
3. T: You have done it, I hope.
4. Mic: Yes. Then the object is totally standing still, when it is not influenced.
5. T: Look, that's what I like to hear. When there is no influence, it is standing still. Very simply put: When the sun stops turning, the earth will ...
6. Jol/Ll: Stand still.
7. T: …stand still. When the sun turns in the other direction, it will ...
8. Jol: In the other way.
9. T: …turn in the other way. That's the idea. Yes? (2s) Yes. What do you think of that idea of Kepler?
10. Mic: Yes, a bit simple. It appears that he did not really think about it, but it is rather clear.
11. T: Rather clear.
12. Mic: Yes.

The model of Newton seems intuitively less clear, as expected:

1. Jol: That "gravity" [said as something revolting]
2. T: Gravity. Yes, how should I picture that?
3. Jol: Yes, that I did not completely understand. But according to me is that the sun also attracts that planet, or something. That it turns because of that.

[...]

4. Nic: Eh, the larger the heavinesses, so heaviness of planet and heaviness of the sun both, the larger the influence. And the larger the distance between the sun and the planet, the smaller the influence.
5. T: Yes. And then he does say how it is, but what that gravity really is...
6. Nic: That is unclear.

The elements of the status diagram did surface in the discussion and, as said before, students were able to write them down afterwards. However, it was not explicitly pointed out during the discussion that an element *of the status diagram* had been discussed, thereby a chance was missed to point out its use as a tool for keeping track of the main thread.

The point that the described regularities still are somewhat vague and in need for specification, which prepares for the next episode, was not emphasised. What the facts were that Kepler and Newton tried to explain was not mentioned. Also the question why Newton had other assumptions for the direction of the influence than Kepler was not discussed. These omissions were probably the result of a derailment of the discussion in which the threat of a premature introduction of laziness and the third law (they were mentioned but recognised in time, before elaborating on them) caused a distraction from the intended course.

Answering the analysis questions

10. The question 'are the given examples (of Kepler and Newton) recognised as specifications of the explanatory scheme' has two aspects. The first is whether the activities in this episode are seen as being part of the process of further specification of elements of the explanatory scheme. The second is whether the examples themselves are clear, so that the explanatory scheme is recognised in the texts on Kepler and Newton.

Regarding the first aspect I think that the main thread of specifying the elements of the explanatory scheme was not recognised, because this thread had not been made explicit and in the final interview nobody indicated to have seen this episode (or any) as part of such a thread. I will elaborate (slightly) on the second reason. (The first has been shown in the first part of this section).

The interview after the introductory course concerned with the recognition of the main thread consisted of shortly reminding students of the consecutive sections of the course by flipping through the student booklet and recalling some noteworthy aspects[6] and asking after each section why that section was done, if they found the transition to that section understandable at the time and if they found the transition to that section understandable in retrospect. All seven students were asked these questions individually in interviews that took about 15 minutes.

The only student that saw the intended reason for investigating Kepler and Newton was Jolien:

1. I: Then a kind of diagrams turned up. Then all of a sudden it was about Kepler and Newton. Why did we do that?
2. Jol: To learn different explanations of motions. How they thought about that. And then to look who was right or was closest to it.
3. I: Why did we do that here?
4. Jol: To.
5. I: Why here I mean? Why after that cyclist?
6. Jol: Well, that we can continue with something like planets and stuff after this.

Merlijn seems to come very close as well:

1. Mer: Ehm, because they have found a way to explain everything what is going to happen. And yes, you showed these diagrams. And with these diagrams you can explain their ideas a little.
2. I: You mean these diagrams, or?
3. Mer: These. But this is rather kind of, this is rather the same. And this they used with Newton and Kepler too.

The reason for investigating Kepler and Newton was that 'they had found a way to explain everything what is going to happen', which means 'explain what is going to happen with moving things', i.e. 'explain motions'. The schemes she refers to in (1) and (3) were two figures from the student booklet. One is the same as figure 5 from chapter 5, the other is a filled in version of figure 4 from chapter 5. She considers them to be

[6] I chose to remind students by noteworthy aspects instead of a short summary of the section, because a summary might already give some insight in the main thread away.

rather the same (3), which means that she recognised that they express the same thing (namely the explanatory scheme for motion), although she does not mention in what way they are the same.

Other students expressed various reasons, e.g. Aisha and Rosa mentioned calculating the trajectory of the asteroid. Carlijn saw a thread from small topics like tea to larger topics like the bicycle rider and finally the largest: motion of heavenly bodies.

As part of the booklet section in which episode 2.1 took place I asked about why the status diagram was used. Most students responded by indicating its use as providing an overview, e.g.

> Car: I think so that you precisely know what Kepler and Newton were really thinking. What their theory was. And that it was just briefly put there.
>
> Mer: Eh, then I thought, this is convenient to put Kepler and Newton in. That you don't have to go looking for their stories how they, ehm yes. That you just could look back at any time whenever you really couldn't remember how things were: Whether it was rotation or heaviness.

In addition some mentioned its use for displaying the difference between Kepler and Newton:

> Ros: Yes, I don't know what I thought, but eh to clarify it. That you can see the differences and, more orderly.
> Mic: To eh, you can see differences well. It is clear, you know.
> I: Differences between?
> Mic: Between Kepler and Newton, influence free not in, eh, like motions. Yes, I think that it eh, well...
>
> Nic: Very clear overview. You also could compare on (...)
> I: Yes. What do you compare?
> Nic: Well, his assumptions with those of his. Difference.

Jolien was the only one who mentioned some reflective function, namely noticing what you have learned:

> Jol: Well, to fill in the things you knew then and to add things whenever you learned something new. To notice what you have newly learned.

To complete this account, Aisha mentioned also some use for calculating influences:

> Ais: Yes indeed. That is in order to summarise a little how you do that and eh, to distil the important things. And with what you could calculate these influences.

From these responses I conclude that most students did not recognise the investigation of Kepler and Newton as a first step in specifying the explanatory scheme for motion as depicted in the status diagram. They can see the use of Kepler and Newton in light of the initial asteroid problem, since both investigated motion of heavenly bodies and seem therefore relevant for the asteroid problem.

Regarding the second aspect of analysis question 10, whether the explanatory scheme is recognised in the texts on Kepler and Newton, I think the separate elements were correctly recognised and identified, but their interrelation had not become clear. Except for the influence free motion, the elements of the explanatory scheme were correctly filled in in the status diagram in assignment 18, but in the evaluation several important points were not made clear: If and how Kepler and Newton applied the explanatory scheme for motion and why Kepler and Newton had different explanations. The use or importance of the influence free motion is not sufficiently clear at this stage. This is in agreement with findings from earlier episodes in which the difficult point of the coupling between influence free motion and identification of influences, from which the use of the notion of influence free motion surfaces, did not become clear.

Since what students filled in in their status diagrams was largely correct, I am inclined to think that a similar discussion of their answers as I suggested before in relation to the responses to the main question of episode 1.5 (see section 4.5) would have been quite possible and appropriate. It would have been possible therefore to point out the implicitly recognised structure of the status diagram in connection to students' input.

Conclusion and suggestions for improvement

The accounts of Kepler and Newton were recognised as having to do with motion like the asteroid problem and possibly as 'theories' in some vague sense about motion, but not as *examples of specifications* of the explanatory scheme for motion. Although elements of the explanatory scheme were recognised in the texts on Kepler and Newton, their interrelations were not. The function of the explanatory scheme for motion as guiding the subsequent programme of further specification of elements of the explanatory scheme (with use of the status diagram as guiding tool) did not become clear. Therefore, from now on a *new* project is unintentionally started for students in which Kepler and Newton will be investigated using a computer modelling environment, instead of the intended continuation of the same project of detailing the explanatory scheme for motion.

The test does not suggest revisions in the design of this episode, only in the execution.

5.2. Episode 2.2: Introduction to the matching problem

What happened?

The episode was not introduced. In the main question and answer phase the computer model should be demonstrated requiring a formula or influence law and illustrating Kepler's assumption for an influence free motion, his notion of influence including his spokes explanation and a Keplerian influence law. The teacher should then invite suggestions for effecting a 'match' from the students. This demonstration happened largely as intended. Students did not suggest any formulas, instead the teacher quickly went from I=0, through I=R, I=R*r and a short discussion why this one cannot be right to I=R/r. One student found this curious:

1. Chr: Why do you have to divide R by r, that I don't get.
2. T: Well, I don't know either. One simply tries something. No, but you have to think of something.

3. Chr: The R stood for rotation of the sun, didn't it?
4. T: I is the influence, R is the rotation of the sun, yes. When the rotation of the sun increases, what will happen to the influence? (3s)
5. Mic: Will increase.
6. T: So, I am looking for a formula that does what I want it to do.

[...]

7. Chr: But why are you going to divide the rotation speed of the sun by the distance to the earth?

The necessity for an influence law for determining the motion was probably mentioned too quickly and too implicitly in the demonstration. The idea that the regularities of Kepler (as they were mentioned in the text students read about him) are still somewhat vague and imprecise and need quantification was not mentioned. Instead it seemed that the context of using a computer model dictated the need for a mathematical formula. The teacher then suggested $I=R^2/\sqrt{r}$ and asked how one can find out whether such a formula is right.

Jolien provided the right answer:

Jol: When the model is moving the same as the earth.

Also Merlijn recognised that trying several values for R was done in order to effect a match, although the fact that she asked about it suggested that she was unsure about it:

Mer: What is the meaning of all this? That it goes the same with the real earth?
T: Yes!

I considered the given explanation understandable for the students. Jolien and Merlijn expressed the idea of 'matching' as a way to know whether a particular influence law is right. It seems fair to think that most other students would agree with that. The teacher was very enthusiastic about this model and also the students were very much involved in whether the 'model planet' would catch up with the 'observed planet'.

Rosa raised an important issue:

1. Ros: But sir, with that formula you only do the influence...
2. T: Yes.
3. Ros: …you only calculate the influence. So really, but [with] the earth you do not see a [difference in the] arrow, so you cannot know whether you were right.
4. T: On the real earth you do not see an arrow. No. So the real earth does not have that, because that influence is in the model. You come up with that influence. Or Kepler came up with that influence. He thought of that.
5. Ros: How can you know whether it is right or not?
6. T: Well, you can't. Only, imagine that it is right, yes? And it all fits beautifully. Then you can say that the best model is a model that... Yes, when is a model the best?
7. Mic: When it has the best effect.
8. Jol: When it most resembles the real.
9. T: When it most resembles the real.
10. Jol: Yes.

11. T: And of course also when I have six planets that result in six different rotation speeds of the sun. Yes, that would be a bit complicated, how things can fit together then. So you want to arrive at one rotation speed of the sun, right? And you also want that once you got the rules, that they also apply to a meteor, that the meteor also fits. So I really want one theory for everything. That I would like. And that is what we are looking for.

[Later this exchange was continued:]

12. T: Aah, you don't get it. Good, good. Tell me, what do you don't get?
13. Ros: So, you have to look which arrow is best?
14. T: No. Not which arrow is best, because you cannot see that. You can look which ... motion is best. You know how the earth is moving. You make a theoretical construction, because you say that the rotation speed is involved, the distance is involved, I think of something with those. Yes? And then I look whether they are moving in the same way. And the best model will fit the best. You have to choose both the best model as well as for instance the best rotation speed within that model. So you have to think of both the best model, which is your theory, and you have to get the right value in your model. So that involves quite a lot of steps. Yes? So that is what we are going to do.

Rosa was thinking of matching the modelled influence to the real influence (3, 13). The teacher explained why motions instead of influences are compared by telling that the 'real influence' cannot be observed, only the resulting motion (4, 14). The teacher does a pretty good job here, but it is a rather difficult explanation, which suggests that the design may be improved on this point. The teacher also uses an argument based on the criterion of broad applicability (11) which is strictly speaking not necessary here, but can be used. The fact that 'influence' is a theoretical construct that cannot be observed in the context of heavenly bodies is somewhat confusing, since it had also been related to observable influences like pedalling or braking.

Perhaps the best response to Rosa's question would have been the first part of what the teacher answered, namely that the 'real influence' is not observable in this case, leaving more fundamental considerations aside whether this is in principle impossible because it is a theoretical construct, or in practice difficult or even impossible. Such a discussion can perhaps at a later stage be meaningful, but not now for it will complicate the introduction.

The intended evaluation was lacking.

Answering the analysis questions

11. It is not very clear for students how a detailed explanatory scheme may lead to predictions of motions, because although the meaning of the matching problem did become clear, the necessity for an influence law did not.

Suggestions for improvement

To the introduction of the matching problem can be added, e.g. when demonstrating the model, that the influence on the observed earth is not depicted because it is unknown, whereas its motion is known.

5.3. Episode 2.3: Influence laws

What happened?

In the introduction students should be able to think of several correct Keplerian and Newtonian influence laws (and possibly one of their own). The question how one can choose between the given alternatives should trigger a recollection of the earlier demonstrated matching problem as a way of approaching this. In the introduction the students read a short introductory paragraph and all came up with several alternative influence laws in question 20 and 21, which were almost all in agreement with the regularities. They mostly varied on the form $I_{Kepler}=R^a/r^b$ and $I_{Newton}=H^a/r^b$ with a and b integers. Most students could not think of additional factors affecting the influence, as was expected. The subsequent investigation of alternative influence laws with computer models was introduced at the beginning of the next lesson (lesson 4) roughly as intended.

In the main question and answer phase the students should test three Keplerian and three Newtonian influence laws (question 23), describe how one can see if some model is Keplerian or Newtonian (question 24) and add the best influence laws to their 'status diagram' (question 25). I expected effecting a match to be fairly easy. Differences between Keplerian and Newtonian models I expected students to come up with were the kind of influence law, the direction of the influence, and the observed motion after the 'test' of making the influence zero by making the relevant parameter (R or H_{sun}) zero.

Students were able to apply a correct matching procedure and came up with correct conclusions concerning which influence law could be suitable. Students did not see influence laws as specifications of regularities, because although this was indicated by the teacher, this was not emphasised (e.g. by using student responses to questions 20 and 21) and is hard to come up with for students on their own. Furthermore no fragments were found in the protocols that indicate otherwise. The only two students that added an influence law to their 'status diagram' did not do so in the box 'regularity', which indicates that they did not think some relation between the found influence law and a regularity was obvious.

Students seemed to have an operational understanding of the function of the parameters in the influence laws, but found it difficult to explain why these parameters showed this functionality. With an operational understanding I mean that students realised the effect of a parameter on the motion simply in terms of some easily observed feature[7]. An example in which a student developed (with some help) a slightly deeper insight into the functioning of a parameter is the following:

In response to a suggestion of the interviewer Merlijn and Mick changed the value of the rotation speed of the sun R by making it negative and later zero. They were asked to explain the motion they observed.

[7] Operationally matching would follow a line of thought similar to the following: 'In order to keep up with the real planet the model planet should move faster, therefore this number has to increase, because I have seen that increasing this number makes the model planet move faster.'

1. Mer: Because it doesn't move. The rotation speed is 0.
2. [Mic: He is not forced to go backwards in time and also not further.]
3. I: But what you also see with 0 is that that red arrow is gone. What did the red arrow signify?
4. Mer: But this [points towards R?] is the rotation speed, isn't it?
5. I: Yes, correct.
6. Mer: Yes, he hasn't got any more rotation speed, is zero.
7. I: Yes, but who hasn't got any more rotation speed?
8. Mer: The earth.
9. I: But what does that, what rotation speed does that R signify? That is not the roation speed of the earth.
10. Mic: Of the sun.
11. I: Yes.
12. Mer: Ooh. [Because] That the sun is turning in the other way, of course, the earth is turning the other way too.
13. I: Yes, precisely.

At first Merlijn thought R indicated the rotation speed of the planet (5,7). This confusion is indeed obvious and should be prevented in a revised design. By making R negative and later zero and pointing out that R indicates the rotation speed of the sun she got the picture (12). Without such guidance their understanding of the parameter R would have remained rather poor. What this example also illustrates is that students sometimes not remember the meaning of the letters indicating variables (R, r or H). More of such instances can be found. If one does not even know what a particular parameter stands for, one probably does not know its function either. At the most one has an operational understanding, which suffices for the matching procedure as such, but falls short of the intended insight.

Students showed obvious enthusiasm and spent a large amount of time on the modelling assignments. Because of time restrictions only Nicole and Rosa finished all questions (up till question 24) in the lesson, the others did not think about the last questions concerning the differences between Keplerian and Newtonian models. In the next lesson this omission was overlooked and not remedied. I discussed the differences between Kepler and Newton with Nicole and Rosa. These discussions led me to believe that the differences between Kepler and Newton may be quite naturally (that is in close relation to student input) put forward in a evaluative discussion of the relevant question (question 23):

1. I: Ok. You are looking at a model of Newton. Ehm. Mention a couple of differences with Kepler. You have seen now three of Kepler. This is probably the first of Newton. Do you notice any differences?
2. Ros: This is different.
3. Nic: Yes, but that is with...
4. I: That is different.
5. Nic: ...Newton the heaviness.
6. I: Yes. It concerns now heaviness.
7. Ros: That other one talked about eh ...
8. Nic: Yes, that was the eh...
9. Ros: What was R again?

10. I: Rotation speed of the sun.
11. Nic: Yes, rotation speed.
12. I: Yes. So that is a difference. What else?

[They mention different values for the used parameters and different matching results.]

A difference between Kepler and Newton these students easily come up with is the difference in the used parameters in their respective influence laws (5, 7, 9, 11). The other expected differences of the direction of the influence and the test of which influence free motion is used (by making the influence zero) did not surface spontaneously. I rephrased the question now more in line with question 23.

1. I: Suppose that, look now you know that this is a model of Newton. But suppose that you don't know that and you wonder: Would this be a model of Newton or Kepler or maybe something else? How could you find that out?
2. Nic: By looking at, yes, the difference we just mentioned. Whether they look at heaviness or rotation speed. That was a difference wasn't it?
3. I: Yes, exactly. Yes, that is one difference.
4. Nic: And, yes I don't know whether you can see it in these models, but what they eh, when there is no influence.
5. I: Hm hm
6. Nic: Ehm
7. Ros: When you make this zero.
8. Nic: When you make that zero.
9. I: Yes, what would you then expect?
10. Ros: With Newton it would go through and with Kepler (…)
11. Nic: Yes, it will go, no with Kepler nothing will happen. And with Newton it will continue straight with the same speed.

The first difference is repeated (2), but after that the expected test of the influence free motion surfaces (4) in which Rosa adds a way to do that by making R zero (7). They also formulate a correct expectation of the outcome of this test (10, 11). The third expected difference of the direction of the influence did not surface after prompting. It may come as a surprise that these students did not notice themselves the difference in direction of the influence although they had investigated already three Keplerian and one Newtonian model and had read the texts on Newton and Kepler in which this is specifically mentioned. I will explain why I think it is not surprising in answering analysis question 12.

In the evaluation the teacher should take stock of several answers and makes sure the main points surface clearly: a quantification of the regularity is necessary in order to predict motion, an influence law is testable by matching, and some feeling for the effects of R and H. This did not happen. The episode was not evaluated.

Answering the analysis questions

12. Students' insight in motion models has deepened somewhat, although not as much as expected or possible. This conclusion is based on the following interpretations of the presented results:

- Students could correctly translate assumptions of Kepler and Newton concerning influences into an influence law.

- Students realised that an influence law is needed to calculate the motion of a planet around the sun, but did not see that it is a specification or quantified expression of the earlier seen regularities of Kepler and Newton.
- Students saw that alternative laws are possible, because all students could come up with several alternative influence laws, although these were mainly unimaginative variations on one form.
- Students did not understand the role of parameters in the models. Their understanding remained on the level of what I called an operational understanding. For deeper understanding some reflection would be needed, which was planned to take place in the evaluation phase, but as was mentioned before did not occur properly.
- Students understood what testing a model entails. The notion that the two moving things should be on top of each other was clear to everyone. I think that students realised that this means that the model should predict the observed motion. They probably attributed some meaning to this activity given their obvious enthusiasm and large amount of time they had spent on this activity. If they had seen this activity as merely a meaningless game of changing a number until two things are on top of each other they would have become bored quite quickly. This is also in line with an earlier result from episode 2.2 indicating some understanding of the matching problem.
- Students could have acquired more feeling for the difference between Kepler and Newton. Although this was not observed to arise without prompting, the ease with which two differences (different parameters in the influence law and different motion in the situation with influence put to zero) could be triggered in the only students that had progressed sufficiently far in the episode in the given time suggested that in a proper execution of the evaluation these differences would have surfaced in most students.

  The apparent difficulty in prompting the third difference (it was not mentioned spontaneously, but had to be introduced), the different direction of the influence, can also be understood. Seeing the direction of the influence as a telltale indicating whether the model is Keplerian or Newtonian requires insight in the difficult point of the coupling between the assumption of an influence free motion and the identified influences accounting for deviations from this motion. Merely mentioning this difference or letting students read about it is not sufficient. This coupling had unintentionally not been addressed so far, thereby making it difficult to appreciate the significance of the direction of the influence. This might also work the other way around: discussing this difference in direction of the influence between Kepler and Newton can clarify the mentioned coupling.

13. The question which type of model is fruitful was not seen to pop-up occasionally.

Suggestions for improvement

What can be done to deepen the operational understanding of parameters to understanding their function and 'background' besides the suggested evaluation of the main activity? Now too much emphasis lies on the evaluation. It would be preferable when the main activity itself fulfils a weightier role in the functions of 'deepening the insight in the what and how of explaining motions, limited to the relevant factors in the influence laws'. Can the main activity be designed in such a way as to prevent mere operational matching? Finding answers to these questions would improve the design of this episode.

The parameter R, the rotation speed (of the sun), is confusing when it is used without its suffix 'of the sun' since rotation speed can mean the speed at which the sun rotates around its axis and the speed at which a planet moves around the sun. This confusion might be prevented by adopting some other term for this parameter.

5.4. Episode 2.4: Laziness

What happened?

The introduction consists of three parts: an introduction (of the introduction), a main question and answer phase (of the introduction) and an evaluation (of the introduction). In the introduction of the introduction students should read about laziness in the context of further specifying the relation influence – motion. Instead of ensuring that students read and understood this part the teacher gave another introduction himself which was largely incomprehensible.

In the main question and answer phase of the introduction a simple Keplerian and Newtonian model including laziness as a parameter should be investigated guided by questions asking to vary the laziness of the earth and look for what happens with the influence on and the motion of the earth, match the motion of the earth by finding suitable sets of parameters and explain why several sets are possible. I expect students in this way to easily observe the effect of laziness on the motion and notice the balancing effect of influence and laziness.

What happened was that the investigation of simple models with the added parameter laziness went well. There were no signs of students getting stuck, like asking questions about the meaning of assignments, but it took a lot of time because students started freely exploring the models instead of directly focussing on the guiding questions, which they only did after being told to by the teacher. Interestingly one group performed all the required tasks for answering the guiding questions during their free exploration, but repeated those tasks when answering the guiding questions. Apparently they did not realise that they had already seen all the ingredients for answering the questions.

As was the case with 'influence' students also tended to understand 'laziness' merely in an operational way. Take as an example of this operational use the following excerpt:

1. I: What does that laziness do. When you change it?
2. Mic: When it is smaller, the smaller the laziness, the faster.

3. I: Yes.
4. Mer: And the larger [laziness is], the slower [the object moves].
5. I: OK. Is that logical or eh, can we understand that?
6. Mer: Yes, we can. It is kind of hard to explain. What Carlijn mentioned about the ball.
7. I: Hm hm.
8. Mer: When it is heavier, it will simply move slower.
9. I: Yes.
10. Mer: So, I see laziness more as heaviness.

Some found laziness difficult to express, some were uncertain about its effect and some identified it with heaviness (like Merlijn did in the last example (10)) or influence. The distinction between influence and laziness was correctly written down and expressed by only two students. When seen strictly operationally, influence and laziness are indistinguishable, of course. Their effects on the motion are similar and can balance.

Although students observed the phenomenon of balancing, they could not explain why this occurred. Their written answers indicated that the phenomenon of R and L (Kepler) and H and L (Newton) as balancing numbers was slowly remarked. Some students chose sets of values for parameters R and L that differed precisely in the same factor. (If R_1 and L_1 resulted in a match, also did $f{\cdot}R_1$ and $f{\cdot}L_1$, with f some constant). This suggests that they at least had an implicit notion of balancing. From the protocols the only example of a developing notion of balancing was the following in which some light dawned on Christiaan. (What Mick was saying here is irrelevant).

1. Chr: I am still only working with the influence. I am changing the influence until it goes right. Not the laziness, you know. With the laziness I don't have to do anything.
2. [Mic: I am changing the laziness.]
3. Chr: Wait a minute. I'll try again. Suppose I increase this one. Than it will have to go slower. This is much slower. But then I can change this again. So, that smaller again, if I am right, no larger, eh, 0,8...
4. [Mic: Oh, he is going to look at his neighbour.]
5. Chr: I turns out the same. Then you can make it the same eventually in that way.
6. I: Hm hm. Yes, so you can choose.
7. Chr: Yes, you can simply choose, You can say: I am going to keep the influence like this, but I do with the laziness, I change the laziness so that it turns out alright.

Christiaan was working on a model in which both the influence (by means of the rotation speed of the sun) and the laziness can be changed. He indicated that he was only changing the influence, letting the laziness unaltered (1). He then decided to increase the laziness, making the correct prediction that the motion should decrease speed (3). He also observed that by changing the influence again (to 0,8) (3), the motion remained the same (5).

Important for explaining the balancing phenomenon is being able to sharply distinguish between influence and laziness, which students found difficult. An example of failing to sharply distinguish between laziness and influence is the following:

1. Mer: Yes. When you increase the laziness, the influence increases too.

2. I: How can you see the difference between influence and laziness in such a model? Can you see that at all?
3. Mer: The influence is this red arrow (...)
4. I: Yes, yes.
5. Car: And the laziness is…
6. Mer: I perceive laziness as kind of the speed of the planet, the ehm earth.

The reasoning during matching did not show arguments from basic ideas. In matching a Newtonian influence law Rosa, for instance, applied the same operational procedure as she did in the case of Kepler by looking at the speed of the planet. Nicole used a new operational procedure by looking at whether the model planet curved too much inward or outward. (‘Increasing this number (the laziness) makes the planet curve more outward’). Such a correct operational procedure sufficed of course for these matching assignments, but did not indicate understanding of why the motion is as it is.

After discussing their answers in the evaluation of the introduction the teacher should recapitulate that Kepler and Newton both attributed various lazinesses to various objects and that the laziness of an object indicates how strongly the object reacts to an influence. He should then introduce the next part by stating that Kepler and Newton tried to establish the laziness of different planets and that the topic of the next part is to investigate how they did this.

During the evaluation of the introduction, which took place two lessons later, in lesson 7 (lesson 6 was used for a test), it became clear that students could not tell what laziness is. This main point was therefore repeated, which at least provided students with a proper definition of laziness given by the teacher and later correctly repeated by Mick:

1. T: No example. What is laziness?
2. Mic: Laziness is how an object reacts to an influence. When it react steeply and moves a lot, than the laziness, it is not very lazy. When it reacts little to an influence, it is lazy.

Unfortunately the vagueness in the original definition was also repeated: It remains unclear what exactly ‘a reaction to an influence’ is or what ‘much movement’ is. The subsequent main activity and answer phase was sketched as a continuation of an investigation into laziness with an extension to more planets. Its main purpose of finding out how laziness can be determined was not mentioned.

This evaluation (of the introduction) illustrated in a way the use of a proper evaluation. It became clear what students had understood of the preceding part (namely little) and gave an opportunity to do something about it (in this case once more explaining what laziness is).

In the main question and answer phase students should determine (the ratio of) laziness(es) according to Kepler, using a model of two planets, guided by a matching assignment that asks for several solutions. A similar application of a Newtonian model of two planets should lead to the conclusion that in this way the ratio L_{earth}/L_{venus} or H_{earth}/H_{venus} cannot be determined. They should then apply a newly introduced way of determining laziness with a Newtonian model of sun, earth and moon, guided by some preparatory questions asking to calculate the ratio L_{earth}/L_{sun} and whether with this model the laziness of the moon can be determined. These prepare for the question of which planets the laziness can be determined in this way, which is meant to lead to the conclusion that in this way only the laziness of heavenly bodies can be determined if they have another object circling around it. I expect students, guided by several questions, to arrive at the conclusion that Newton's assumption (that laziness equals heaviness equals mass) was right, whereas Kepler's was not.

The main question and answer phase took more time than expected. Many students first had to finish earlier questions. Students were restless. Although they remained mostly on-task, they were less concentrated.

All students could find one correct solution for a match in the Keplerian model for two planets. Only some mentioned a second solution, which underlines the earlier finding that the notion of balancing was not clear. If it had been clear at this stage, a second solution would have been easier to find and write down. All students found a correct ratio for L_{earth}/L_{venus}.

Five students found a correct solution for a match in the Newtonian model for earth and Venus. Nicole and Mick even mentioned the right condition for a solution, $H_{sun} = 900$ and $H_{planet} = L_{planet}$, together with an example. The other students did not answer this question. Four students seemed to understand the idea that the ratio L_{earth}/L_{venus} could not be determined with this model. Two did not answer the related question, one answer I found incomprehensible:

> Mer: No, when you look at his results you don't see any similarities.

And one answer was not true:

> Ros: Yes, the laziness of the earth is 2x as big as that of Venus. You can simply see that.

Most students arrived at correct values for the ratio L_{sun}/L_{earth} in their matching of the Newtonian model for sun, earth and moon. The intended conclusion that the laziness of heavenly bodies can only be determined by matching motions when they have some object circling around them seemed to be reached, for students gave correct answers to the relevant questions. In response to the question whether with the Newtonian model for sun, earth and moon the laziness of the moon could be determined four students were able to write down a correct answer. Take as a typical example the answer of Rosa:

> Ros: You know something of the sun by looking at the earth that circles around it. And information on the earth by the moon that circles around it. The answer is therefore 'no', because you need a planet that circles around the moon.

And also most students correctly stated that only of planets with a moon the laziness can be determined in this way. However, both responses were not given without help of the teacher and in fact echoed the given help.

Most students that managed to get this far in the episode (5) arrived at the conclusion that Keplerian laziness does not equal mass. Three students drew a conclusion regarding the Newtonian idea that laziness equals heaviness equals mass. Jolien concluded that

Newton's assumption is correct (but she did not add this to her summarisation figure), Aisha concluded that Newton's assumption is incorrect because the ratios of H did not precisely equal the ratios of m (there was less than 1% difference) and Nicole concluded that Newton's assumption was incorrect because of a calculation error she made.

In the evaluation the answers should be discussed. The teacher should emphasise the main point, which is the role laziness plays in relating influence to motion. This relation is finally quantified in a text students should read in which the rule 'deviation = influence/laziness' is introduced. I expect in the discussion the question 'which type of model is best?' to slowly surface. This evaluation did not take place. The class continued with the next episode, episode 2.5, omitting the questions most had not finished. The introduction of the rule 'deviation = influence / laziness' was skipped altogether at this stage. The point that this rule is a specification of the relation influence – motion was not addressed. At an earlier stage the question whether one type of model was better than the other surfaced explicitly:

1. Ros: Has already been proved who is right?
2. T: Well, that is really the question for you. Do you have an idea who is right? Which one fits best?
3. Ros: I'd say, I find Kepler quite logical.
4. T: Yes, yes. You find Kepler quite logical and I do so too. And Newton especially with that 2, that ... seems to fit better...
5. Ros: Yes.
6. T: …but he has that illogical story. So that is a bit of a problem...
7. Jol: But when I was at home, before I read about Newton, I thought it would come to a stop, when I hadn't read about Newton. Then I thought it might as well go straight on. That seemed more logical.
8. T: Ah, yes.
9. Ros: Yes, but I find, I don't know. Kepler on that bit about these spokes and stuff, that I find quite logical, but ...
10. T: Yes.
11. Ros: …only, I might also say that they would continue on, but it seems like Kepler did not think things through. Like he wanted to give a kind of too simplistic answer.
12. T: Yes.
13. Jol: He came before.

[...]

14. Ros: But is it the case that one of these two is right? Or is it someone else? Or is it undecided, does one not yet know at all?
15. T: In the end, when you look back with current knowledge they both are not completely right, unfortunately.
16. Ros: But they do know now? Or are these other...
17. T: They know now much better. When you apply the theory of Kepler or Newton, you will encounter errors, deviations. I think the deviations in the case of Newton are a little smaller than those of Kepler. That we also have seen, haven't we?
18. Jol: Yes.
19. T: And I think it is a bit mixed, isn't it. I think the story of Kepler is somewhat more logical and Newton fits somewhat better, so yes.

The question if already had been proven who was right (1) is later sharpened by expressing all possible situations in (14). The question is not answered by the teacher resulting in a discussion about the strengths and weaknesses of the two types of model.

Answering the analysis questions

14. Students' inability to explain why influence and laziness exhibit a balancing effect on the motion and what laziness is, was disappointing. This meant that students did not acquire a clear picture of the different functions of influence (or indirectly the parameters R or H) and laziness.

15. The rule deviation = influence / laziness had not been introduced at this stage. Some students might have read about this rule in the student booklet. However, given the earlier seen result that students did not really understand influence and laziness, their grasp of this rule cannot be firm.

16. The question which type of model is fruitful was seen to pop-up explicitly only once. What was apparent from their investigation of the Keplerian and Newtonian models is that students had not yet decided which type was to be preferred. Although sometimes students arrived at some conclusion regarding the plausibility or validity of some model, this did not yet tip the balance in favour of one or the other. E.g. the idea to assume rest as influence free motion was considered more plausible than the Newtonian equivalent by some and Kepler's assumption that laziness equals mass was considered invalid by others. Since both Newton and Kepler were therefore still in the race one can say that the question which type of model is fruitful had not yet been answered. Whether most students really wanted this question to be answered is hard to say.

Suggestions for improvement

In answering the guiding questions related to the investigation of the computer models the same actions were performed as were done before in a free exploration of the same models. I think this repetition of tasks suggests that the designed guiding questions are indeed necessary to force students to articulate their findings and also that these guides are not too far from the path students would have taken by themselves. The questions seem 'logical' or natural, which is a good sign.

Something should be done to enhance the understanding of laziness beyond the operational level. The matching assignment as it is now can be accomplished with an operational procedure, putting too much emphasis on the guidance from the teacher during the assignment and its evaluation afterwards to raise this to a more meaningful insight. It would be preferable if the assignments themselves already require deeper understanding. How this can be done remains an open question for now.

5.5. Episode 2.5: The precise relation between influence and motion.

What happened?

In the introduction the relation with the main thread should be addressed using the status diagram. What happened was that no introduction took place.

In the main question and answer phase an example of the Newtonian or Keplerian graphical way of constructing subsequent positions should be explained and demonstrated by the teacher, read about in the booklet, illustrated with a computer model depicting a quick succession of constructions of positions of a planet, and applied in one Newtonian (question 89) and one Keplerian (question 88) linear case. The teacher should emphasise the main point, that it is possible in principle to construct the motion from a given influence law, not the specific details.

Students read the complex text on constructing motion from known influences as homework. The next lesson this text was discussed where it became clear that students understood some details, missed other details and one student explicitly asked what its meaning was. These details (amongst which the use of the rule deviation=influence/laziness that should have been introduced in episode 2.4, but was skipped) and the meaning of the episode (in this way any type of motion can be constructed) were discussed. After this the topic of constructing motion from a given influence law was extensively explained by the teacher[8] using the blackboard.

The explanation largely followed the text in the booklet and scenario, but was in some ways confusing. The teacher talked unnecessarily about ‘velocity’ and used the word ‘change’ as a synonym for ‘deviation’ (from the influence free motion). The term influence free motion itself was not used, neither was the explanatory scheme for motion explicitly mentioned, although there were opportunities to repeat it. The concepts laziness and influence were still not clear, as was seen in earlier episodes. Take for example the following response to a teacher question:

1. T: [...] What is laziness again?
2. Car: Laziness?
3. T: Just, in plain... What do you feel with the notion of laziness? Something is very lazy...
4. Ais: Heavy...(...influence...)
5. T: Yes, and when something is very lazy, it will react very ...
6. Car: Bad.

The two students who reacted, Carlijn and Aisha, did not come up with the answer themselves. Carlijn merely filled in an answer of the teacher (6). It is apparently still quite difficult to come up with a description of laziness.

Next the students investigated in pairs a model depicting a quick succession of constructions of positions of a planet guided by an assignment. They found interpreting what they saw on the screen difficult and needed a lot of help in doing so.

Students applied the demonstrated graphical construction technique in the next two assignments (88 and 89). Eventually students were able, with quite some help, to give fairly correct answers to these assignments. Applying the rule

[8] The teacher later indicated that part of the reason for setting this text (which was expected to be too difficult to be comprehended without proper introduction) as homework was to provoke the need for his explanation. Giving students an assignment with the expectation that they will not be able to do it at all is of course in sharp contrast with a problem posing approach.

deviation=influence/laziness to these simple linear Keplerian and Newtonian constructions succeeded quite well.

The meaning of these assignments was not clear at first. Take for example the following two fragments:

1. Car: No clue how to do this.
2. Car: I have no clue how to do this.
3. Mer: No, me neither.
4. Mer: I don't get at all what I am supposed to do.
5. Car: Is that the influence? (10s) So what do you have to do? (4s) Oh, this arrow indicates deviation. (20s)
6. Car: Is this arrow 2 centimeters? Otherwise I won't know too... I think this... How can you draw a deviation arrow?
7. Mer: That's the influence, isn't it? Influence is always in that direction, isn't it. Then these arrows also go in that direction? That is only going straight on.

[...]

8. Mer: Sir, why are we skipping steps?
9. T: Yes?
10. Mer: Why are we skipping steps?
11. T: We do not skip that much. You are doing this now, so that you can understand how the program works, after which you will wonder about other things. I found out that you were filling in these things, but did not undestand what happened with such a program.
12. Mer: Now I don't get at all what we are doing.

Both the meaning and certain details of the assignments were not clear. These students did not know what they were expected to do (1, 2, 3, 4, 12) and wondered about specific details (5, 6, 7). Merlijn asked why steps were passed over (8, 10), which indicates that the assignment apparently did not fit in the main line that she had perceived.

Although these and other difficulties were encountered, students remained on-task and did not abandon their work in frustration.

The main point that motion can in principle be constructed when the influence (law) is known was not emphasised by the teacher during these assignments and was not spontaneously recognised by the students since none mentioned it during the lesson or in the interview about recognition of the main thread at the end of the course.

In the evaluation the questions should be discussed and the main point again emphasised. The quick and bright students should continue with investigating the effect of the time step size (question 90). This did not take place. Not everyone finished the questions. Some students did manage to get as far as the last question (question 90). In relation to that question students noticed that decreasing the time step size gave better results in the sense of a more fluent and exact motion. They could not explain this in detail, as was expected.

As was seen, the execution of this episode differed strongly from the intended design. Apart from the reason encountered before (my inadequate preparation of the teacher) here this was due to a lack of clear instructions in the scenario. These were not worked out to the same extent as for other episodes, because of the optional character of this episode. Furthermore the teacher and I explicitly differed in our goals for this episode. My aim was that students should arrive at some confidence in that given influence laws can lead to motion (by means of a detailed technical exercise), whereas the teacher found the details involved in this exercise itself important. This had a large impact on the outcome of this episode.

Answering the analysis questions

17. Students cannot be expected to fully understand how a motion model may lead to prediction/explanations of motion, because of two reasons. Firstly, this is a new and difficult topic that only after an explanation, reading a text, watching a computer demonstration, working trough some examples and discussing their answers can be expected to be somewhat clearer. Since the execution deviated from the plan, this could no longer be expected. The main point of this episode was not clearly emphasised and no indications were found that students recognised it by themselves. Secondly, students lost themselves in details, which is in stark contrast with the episode's goal that they should trust that the motion of an object can in principle be determined from given influences and type of model, not how this is precisely done. Results from earlier episodes had already shown that the concepts of deviation, influence, laziness and influence free motion were shaky. Getting lost in details in this episode was also related to this unstable grasp of these basic concepts.

18. The question which type of model is fruitful did not explicitly come up. A similar account as was given in section 5.4 in the answer to analysis question 16 can be given here as well: both type of models are still in the race.

Suggestions for improvement

The execution of this episode does not give additional empirical evidence for the claim that this episode can fulfil its function. I still believe that it can, based on the arguments from the scenario, but these were not tested. This episode suffered from 'fall out' from the previous episodes, in the sense that earlier shortcomings were also felt here. It is therefore hard to find suggestions for improvement.

5.6. Conclusion main theme 2

Before drawing some conclusions concerning theme 2 as a whole I will summarise the answers to the analysis questions related to the various episodes in the following table, see Table 2.

Students knowledge is somewhat extended, but not by detailing the explanatory scheme for motion. This main thread was not recognised. Understanding the mechanics content, notably the concepts influence, laziness, influence law, and second law (or the rule deviation=influence/laziness) turned out to be disappointing. This is not that surprising because of the faults in making the main thread clear and explicit. A good execution would have resulted in better results concerning the mechanics. Some indications were found to justify this claim, notably those instances that in students' responses elements were found allowing a natural (meaning in close relation to student input) continuation in the desired direction. Even so, it remains to be seen whether students would have recognised and responded in the expected way to such a 'natural continuation'.

Main theme 2: Extending students' knowledge.		
Function of main theme: Extending students' knowledge by detailing the explanatory scheme to arrive at empirically adequate models for explaining the motion of heavenly bodies, resulting in a question concerning the fruitfulness of the specific schemes and models.		
Episode	Analysis Questions	Answers
2.1 Transition to Kepler and Newton	10. Are the given examples (of Kepler and Newton) recognised as specifications of the explanatory scheme?	The main thread was not recognised. Most elements were correctly recognised and identified, but their interrelation had not become clear. The use or importance of the influence free motion is not sufficiently clear at this stage.
2.2 Intro-duction to the matching problem	11. Is it clear for students how a detailed explanatory scheme may lead to predictions of motions?	No, because although the meaning of the matching problem did become clear, the necessity for an influence law did not.
2.3 Influence laws	12. Has students' insight in the *what* and *how* of specifications of the explanatory scheme for motion deepened, or more concretely:	Students' insight in motion models has deepened somewhat, although not as much as expected or possible, because:
	- Can students translate assumptions of K and N concerning influences into an influence law?	Yes
	- Do they understand the function of an influence law?	Students realised that an influence law is needed to calculate the motion of a planet around the sun, but did not see that it is a specification or quantified expression of the earlier seen regularities of Kepler and Newton.
	- Do they see that alternative laws are possible?	Yes.
	- Do they understand the role of parameters in the models?	No. Their understanding remained on the level of operational understanding.
	- Do they understand what testing a model entails?	Yes.
	- Do they get more feeling for the difference between K and N?	No, but they could have.
	13. Does the question which type of model is fruitful slowly start to pop-up?	This was not seen.
2.4 Laziness	14. Do students know what laziness is and does?	No.
	15. Do they know the rule deviation = influence / laziness?	No.
	16. Does the question which type of model is fruitful slowly start to pop-up?	Yes, although seen only once.
2.5 The precise relation between influence and motion	17. To what extent do students understand the method of graphically constructing motions from given influences?	Students have little sense that the motion of an object can be determined from the given influences and type of model. They were rather lost in the details, which use did not become clear.
	18. Does the question which type of model is fruitful come up?	No.

Table 2: Summary of answers to analysis questions of main theme 2

The project of comparison of alternative types of model was successful in the sense that students did manage to use the criteria of empirical adequacy and plausibility for choosing between models and both types of model remained feasible as alternative. The question concerning the fruitfulness of these types of model was hardly ever explicitly raised, but seems to be still relevant because students have not yet decided which type of model is more fruitful.

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

6.1. Episode 3.1: Reflection on types of model

What happened?

The teacher should introduce this reflection by remarking that in order to decide how to continue it would be useful to look back for a moment. There was no such introduction.

The questions (question 44 - 49) of the main question and answer phase, in which all previous main points of the introductory course are captured, were supposed to be done in the thinking-sharing-exchanging format. The thinking phase was done as homework and students were given a procedural reason for paying much attention to this homework, which they did.

In the sharing phase of the evaluation the students should share in small groups their answers to questions 44 – 49. Here they were expected to complete missing elements in their answers and try to reach agreement within their groups on what proper answers should be. What happened was that the homework was shared in groups of three or four students. Sharing consisted mainly of reading out one’s answers and adding or completing one’s own answers when one agreed with another answer. Earlier written down text was seldom changed nor challenged. In the conversations students seldom disagreed, although they sometimes should have when answers diverged.

In the exchanging phase of the evaluation the findings of the groups should be exchanged in the class. Possible wrong or incomplete group answers can now be corrected or completed. The conclusion that both kinds of model can be argued for at this stage also can provide the basis for the continuation in the next episode. The teacher should ensure that the mentioned conclusion surfaces in as close a connection to the students input as possible, which is, needless to say, quite a challenge. He also should introduce (or if possible even point out in some group response) the additional criterion of broad applicability that will allow for a feasible test of the types of model by applying them to other motions, e.g. motions on earth. In that way the still open question of which kind of model is to be preferred can perhaps be answered as will be tried in the next episode.

It followed from the written answers that the central question of the introductory course (question 44) and the function of the explanatory scheme in answering that central question (question 45) had not become clear. Only one student mentioned the explanation of motion in response to question 44, others mentioned for instance ‘what is motion' or 'what is the connection between influence and motion'. No one could clearly state what the explanatory scheme is. Two examples are:

> Mic: A scheme with the regularities and the change. The difference between the influence free and the influence.
>
> Jol: A scheme in which a situation of a motion is depicted and all factors that are relevant.

The students seemed to equate the explanatory scheme with the figure depicting the scheme (which is not surprising given that the word 'scheme' already suggests some depiction), and not with the three lines stating the scheme in the student booklet I would have expected as an answer.

The subsequent investigation of Keplerian and Newtonian models had come across better, since students could correctly point out differences between these types of model (question 46) (mainly the different influence laws were mentioned, but also other differences) and they fairly well understood why and how that investigation took place and with what results (questions 47 and 48). Amongst the students some implicit criteria like plausibility and empirical adequacy for estimating the value of a type of model (question 49) could be found. Mick and Merlijn mentioned the plausibility of the influence law:

> Mic: And I found about the rotation speed of the sun of Kepler and the mass [he means heaviness] of Newton, I found both good arguments, you know.
>
> Mer: Also Newton is talking about heavinesses, the laziness and Kepler about rotation. I don't believe that the rotation of the earth has got anything to do with the influence, unless the earth would start rotating real fast.

They argued that Kepler's and Newton's ideas about what the influence depends on are both credible (Mick) or one is not (Merlijn), which is important for an influence law.

Empirical adequacy could be recognised in the following statements by Mick, Merlijn and Aisha:

> Mic: But Kepler [he means Newton] had a better mathematical influence law, one that matched exactly on that computer.
>
> Mer: I am for Newton, with power of r is 2, because it fitted best in that assignment.
>
> Ais: I would choose Newton, because these models match better [with reality] than the models of Kepler.

The same students used the argument I expected to be difficult, namely that Newton's assumption that laziness equals heaviness equals mass is right while Kepler's that laziness equals mass is not, and that this suggests that Newtonian models are preferable. Nicole further qualified this argument:

> Nic: Well yes, in certain aspects I think he is right, but for example Kepler, that laziness equals mass which turned out wrong, his assumption, that does not say that much, because that was with one influence law, so it might be right for another influence law. So that is why I was still vacillating.

I think this is quite a subtle argument. The fact that she picked it up from the teacher slightly diminishes but in no way negates her achievement.

Apart from these intended criteria students also mentioned as criterion the believability of the assumption for an influence free motion, which was also slightly encouraged by the teacher. The criterion of broad applicability was not mentioned.

In the evaluation/exchanging in the class only question 49 was discussed, with an emphasis on which model was best. As was seen, students made use of expected criteria in their written answers, but these were not emphasised and made explicit by the teacher. A clear summary of the answers to the preceding questions was not made.

Students were uncertain about which model is preferable (and why!), which is good. Both types of model are still in the race. Mick and Nicole wrote:

> Mic: I can't choose

> Nic: I really don't know yet where my preference lies.

Aisha indicated for both Kepler and Newton why she would choose for either. Merlijn argues extensively for Newton. Carlijn prefers Newton based on the laziness equals heaviness equals mass argument. Jolien and Rosa did not answer question 49. So only Merlijn had at this stage made up her mind. The teacher mentioned that there seemed to be a slight preference for Newton because of the more precise matching results (empirical adequacy). The message that both kinds of models are still in the race remained implicit, but seemed clear. Otherwise students would have expected some conclusion indicating Newton as the winner. An idea for further investigation was now introduced without relating to student input and without it being clear that it was an idea for further investigation.

Answering the analysis questions

19. The criteria for valuing models and types of model did not surface clearly. Although implicit use has been made of the criteria plausibility an empirical adequacy, this use was not made explicit. The fact that students made use of the intended criteria at all is encouraging, given the earlier shortcomings and difficulties and the deviations in the execution of this episode. This indicates that these criteria are quite robust and intuitive, as was also seen in the first trial (see chapter 4, sections 2.2.2 and 2.3.2).

20. A strategy for further investigation did not surface at all, but could have surfaced in the way I will describe in the part 'suggestions for improvement' in this section.

Concluding remarks

Apart from the expected criteria students used another criterion, namely the believability of the assumption for an influence free motion. This is not a correct criterion, for this assumption cannot be separated from the identified influences. To realise that this is a mistake would require understanding of the difficult and subtle point of the coupling between assumption for influence free motion and identified influences, which is the basic idea of the explanatory scheme for motion. In the first two themes was already seen that this idea had not come sufficiently across, which was confirmed by the students' responses to the reflective questions in this episode. It is therefore not surprising that this particular mistake was made here.

The central question of the introductory course and the function of the explanatory scheme in answering that central question have not become clear. The subsequent investigation of Keplerian and Newtonian models has come across better, since students can correctly point out differences between these types of model and they fairly well understood why and how that investigation took place and with what results. Amongst the students some implicit and explicit criteria for estimating the value of a type of model were used. Unfortunately this was not clearly summarised in a class discussion at the end and it did not function as a guide for further investigation although it might have, as I will try to show in the next part of this section.

Suggestions for improvement

The exchanging could have been done more naturally, i.e. using student input, but the scenario was also not clear or lacking on this point. This episode might have been evaluated in a way that summarised and emphasised the main point of how to choose between types of model, addressed the mentioned wrong criterion, introduced the criterion of broad applicability and provided for a perspective on or even motive for the next episode. A possible way would have been the following:

> *We agree that it is not decided which kind of model (Keplerian or Newtonian) is preferable. We have seen some criteria (assuming that the mentioned criteria have been highlighted in an earlier exchanging of students' answers) with which we could look at the quality of a model. Who has got some idea of how to continue? What can we do to find out which kind of model is to be preferred?*

When this proves to be too open, the following question might be helpful:

> *We could look to other influences and/or other motions. Has someone got a suggestion?*

Then a discussion could follow of how some given concrete suggestion would shed light on the question whether Keplerian or Newtonian models are to be preferred. For example when someone suggests investigating some other motions, it can be shown that when a model describes and predicts this motion also correctly (as it did in the case of planetary motions) this model would rank higher on the criterion of broad applicability (as well as the criterion of empirical adequacy).

In retrospect the lack of critical sharing of answers amongst students is not surprising since the design did not provide an additional assignment related to the sharing although the used interaction structure 'thinking – sharing – exchanging' (see chapter 4, Table 7) explicitly calls for some 'deepening' assignment. The task to try and reach agreement about the answers is not enough for students to critically evaluate each other's answers. This omission in the scenario should be corrected in a revised edition.

6.2. Episode 3.2: Introduction to a choice between types of model for a situation on earth

What happened?

In the introduction the main thread should be emphasised, that by applying Kepler and Newton to situations on earth we try to find out more about the value of these two types of model. The introduction failed to make the relation with the previous episodes clear. The reason for applying Kepler and Newton was not introduced, which was very unfortunate since the previous episode failed to result in a plan for further investigation consisting of an application of Kepler and Newton to situations on earth. This failure might to some extent have been repaired by a proper introduction here.

In the main question and answer phase students should work in a group on one example guided by questions asking to apply step by step a Keplerian and Newtonian model to the example. One group worked on the bicycle example (with the related questions 50 - 54), another group on the hovercraft example (with the related questions 60 - 64).

With some help, which included a graphical construction showing the resulting motion of one opposing influence, questions 50 - 53 were answered as intended. The response to question 54 showed a notion that Kepler's model might be improved by changing its assumption for an influence free motion. Take as an example the following answer, which is typical for this group:

> Mer: Kepler is not right. You could make it right by changing the influence free motion.

The other group also answered questions 60 - 63 as intended. Their answer to question 64 reflected the 'help' given to these students. This group was by a confusing explanation mistakenly led to believe that Newtonian models had to take account of some aftereffect of the push the moving object had received in the past[9]. Before this explanation they did not show any signs of thinking in this direction. These students were now led to believe that Newtonian models exhibit problematic behaviour, whereas they did not mention any problem with the Keplerian model. The same opinion was also expressed by one of them (Mick) in the FCI items interview at the end of the course: an unfortunate explanation indeed!

In the evaluation the groups' findings should be exchanged so that everyone has seen two examples. Students should then answer questions why Keplerian and Newtonian models have been applied to motions on earth (65), what their conclusion was concerning the applicability of Newton and Kepler on a situation on earth (66) and what they could say about the value of these two kinds of models in general (67). I expected that these questions would guide students to the conclusion that applying Kepler to the used examples of motion lead to a problem in the sense of that it predicted a motion that is known not to occur. Newton did not give such a problem and is therefore broader applicable. The teacher should sharpen the answers keeping the criteria plausibility,

[9] The idea of introducing some way of taking account of aftereffects of influences from the past might be a way to repair *Keplerian* models.

empirical adequacy and broad applicability in mind. He should then end by stating that since we now value Newtonian models more than Keplerian, we can try to solve the initial asteroid problem using a Newtonian model (with the best influence law we encountered).

In the evaluation the group work was exchanged in a class discussion, which also showed that the problems that applying Kepler led to had not come across in the hovercraft group. This was at this stage not addressed nor repaired. The following fragment illustrates the misapprehension of Newton and uncertainty of Kepler. Mick reported the findings of his group, which is the hovercraft group:

1. Mic: Yes, what did we find? I was about to say that. That… so it moves with constant velocity straight on, so it would appear that this Newton is right, but he first gave a push before it moved with constant velocity straight on, so there had been an influence in the beginning.
2. T: Can you follow this?
3. Ais?: Yes… a little bit.
4. Mic: And yes… so it surfaced that, one should not only look at the moment itself, but also what had happened in the past, for example looking at that push, which made it move straight on.
5. T: Okay, and when you look at the conclusion, what is your conclusion?
6. Car: That … of Newton is kind of right, but in the beginning … it is not totally complete. He only looks at what happens after, but not before.
7. T: So Newton is right, but you have to properly look at the past. And Kepler … is right or not so?
8. Car: Ehm … well…
9. Mic: Yes.

So according to this group Newtonian models are incomplete (6) taking no account of aftereffects of earlier influences (4) and Keplerian models trigger some uncertainty (8). Although the bicycle group did find the expected problems with Kepler and these were reported in the class, this was not emphasised and did not result in revising the written answers of the hovercraft group (it literally did not register).

During the same discussion the concluding question 65 was answered collectively. Although questions 66 and 67 were skipped in this discussion, most students had written down their answers. The responses to the question of why it was tried to apply Keplerian and Newtonian models to motions on earth (65) did seem to indicate the expected reason, since they all mentioned something like ‘universal theory’, but these answers echoed the answer given by the teacher.

Students’ written conclusions concerning the applicability of Newton and Kepler on a situation on earth (question 66) indicated that the notion that the model of Newton is better applicable to situations on earth had not clearly surfaced. It could only be recognised in three written answers. Only one student explicitly stated that the Keplerian model led to problems.

None of the students gave the intended reason for preferring Newton over Kepler (question 67), which is that since Newton is also applicable to earthly situations it is more broadly applicable than Kepler.

Students were clearly involved in the project of deciding who is right, Kepler or Newton.

Answering the analysis questions

21. Students can not give the intended reason to value Newton above Kepler. The group involved in the bicycle assignments did notice that applying Kepler to the motion of a bicycle encounters (perhaps solvable) problems and that applying Newton does not. However, since they did not state this in their concluding answer to question 67, it is doubtful whether they recognised the importance of this observation. The group involved with the hovercraft, in contrast, saw mainly problems with applying Newton, which can be attributed to the unfortunate explanation of the teacher and to a shortcoming in this example that will be discussed below. Some intended criteria, as well as a not intended criterion, for valuing models were used, but these were not highlighted and explicitly discussed and therefore did not function clearly enough as a basis for a reason for preferring Newton above Kepler.

22. Students did not see the reason for applying Kepler and Newton to a situation on earth. Although they were able to write the intended reason down, this answer could have been merely an echo of the answer supplied by the teacher. Additional information is provided in the interviews at the end of the course. In these interviews none (with the possible exception of Nicole) could explain why the transition to situations on earth had taken place. I surmise that if the written down response to question 65 had been students' own response, more students would have remembered this answer during the interview.

23. The application of Kepler did not recognisably (for the students) lead to problems. See also my earlier remark in response to analysis question 21.

Conclusion and suggestions for improvement

Answers to the analysis questions briefly recapitulated here:

- Students cannot give the intended reason to value Newton over Kepler.
- Students do not see the application to situations on earth as an additional way to find out more about the value of the two types of model.
- The application of Kepler did not recognisably (for the students) lead to problems.

show a lack of success of this episode. This can be attributed to earlier malfunctions in the design that made itself felt here, deviations from the planned execution and omissions in the scenario.

The earlier failure to elicit a strategy for further investigation in episode 3.1 made itself felt here. In section 6.1 I argued that this strategy might have been elicited because the condition was present that both Kepler and Newton were considered to be still in the race. Even without students coming up with a strategy themselves, a proper introduction of episode 3.2 might have repaired to some extent the failure of episode 3.1. Students are visibly involved in the project of deciding who is right, Kepler or Newton, from which a further investigation can be motivated by using or introducing the criterion of broad applicability. The scenario was unclear in this particular point of explicitly applying the criterion of broad applicability.

Another earlier failure that was felt here was that the coupling between influence free motions and identified influences has not been understood. This resulted here in the unintended use of the criterion of 'implausible assumption for the influence free motion' that Newton had been accused of.

An omission in the scenario was how to use, and the importance of using, criteria to determine the value of the two types of model. Students did use (intended and not intended) criteria. It therefore seemed not too difficult to highlight these criteria and use them more explicitly in answering the questions, as was also discussed in section 6.1. This could also clarify the main thread: Application to earthly situations can be seen in light of the criterion of broad applicability. I expect that when the scenario is revised in this direction this episode can better fulfil its function.

A shortcoming in the scenario was a confusing element in the hovercraft example, that did not occur in the bicycle example. In the case of the bicycle rider the Keplerian model led to an obviously wrong prediction of the motion after the bicycle rider stops pedalling (namely an instantaneous reversal of direction and speed). In the case of the hovercraft the motion the Keplerian model predicted after switching on the propeller could be 'continuing in the same direction with greater constant speed, for which some acceleration (instantaneous, very quick, …) would be needed. Newton would predict continuous acceleration. When one does not look at what happens the moment the propeller is switched on, but some moments later, one sees that the motion predicted by Kepler is more like the actual observed motion than the one predicted by Newton. So Kepler appears to be in better shape than Newton (which is of course due to the no longer negligible air friction balancing the force of the propeller). This interpretation of the situation depicted in this assignment was not intended but seems quite obvious in retrospect. This question should therefore be revised to account for this unintended possibility, in such a manner that students are unavoidably led to the conclusion that applying Kepler to some well chosen situations on earth leads to problems, whereas Newton does not.

6.3. Episode 3.3: Asteroid problem, mechanicism and transition to the regular course

What happened?

In the introduction the teacher should recall the initial asteroid problem and the (implicit) promise that this problem would be solved in this introductory course. He announces that this will now be done using a Newtonian model with the best influence law. He also announces that an additional argument for why mechanics is important will be encountered that returns to the earlier seen example of the dissolution of sugar in tea.

What happened was that the teacher did not indicate that students were returning to the asteroid problem, but that they were to continue with an application to an asteroid. The mechanicism part was not introduced here nor as wrapping-up of the asteroid problem part of the episode. Instead the teacher directly started to give an explanation of mechanicism.

In the main question and answer phase students should investigate a Newtonian computer model of an asteroid, the earth and the sun in which they are meant to recognise the various elements of the Newtonian specification of the explanatory scheme for motion. The conclusion students were expected to reach was that whether the asteroid hits the earth depends entirely on the starting conditions. The relevant questions 68, 71, 72 and 73 were answered as expected and with little help from the teacher or researcher. Students can therefore recognise the elements of the explanatory scheme in the code of a Newtonian model of an asteroid. The expected conclusion was not found in response to the relevant question (77) nor in students' conversations and also not in any discussion of these answers (since that was lacking). In response to question 77 (the students who managed to get that far) gave 4 or 5 values for the mass of asteroid and earth with which they collide. In retrospect this was not surprising since varying other initial values like velocity or position was a new aspect in this computer model, that had not been emphasised enough (it was only mentioned in the booklet). This made the intended conclusion more difficult to surface.

Next the topic of mechanicism should follow as part of the main question and answer phase.

Students should read a text in which mechanicism is introduced. That matter can be though of to consist of moving and interacting particles and that macroscopic change can be understood in terms of unchanging particles is illustrated with the example of sugar dissolving in tea. Students answer questions about what they imagine these particles to be like (question 82), what will happen with the particles during dissolution (question 83), why this would explain the observed phenomenon that solid sugar 'disappears' (question 84), why dissolution would go quicker when the tea is stirred (question 85) and why the dissolution would go quicker when the temperature is higher (question 86). I expect the students to come up with perhaps ingenious answers to questions 82 – 85. The last question is probably too difficult. It is meant to show that a plausible answer is possible, although it may have to be brought in by the teacher.

Unfortunately the teacher did not clarify what microscopic explanations of macroscopic phenomena entail, let alone the role the mechanics of particles plays in those, but jumped to the philosophical consequences regarding free will that a mechanicistic or deterministic perspective may lead to. The given explanation on mechanicism focussed on different points than the intended role mechanics might play in understanding all change. It glossed over ideas I would expect far from obvious, namely that matter can be thought to consist of moving and interacting particles and that macroscopic change can be understood in terms of unchanging particles (that is to say the only thing that changes in the particles is their position and velocity). Students can not be expected to have picked up these ideas from the explanation.

In the evaluation the teacher should take stock of the students' answers concerning the asteroid problem, check whether they consider this solved, take stock of some answers concerning the mechanicism and bridge the introductory course to the regular course. This was not done.

Answering the analysis questions

24. Students have little appreciation for the power and range of Newtonian motion models. Appreciation was supposed to increase in this episode by the mechanicism account, which, given the way it was executed, cannot be expected to have fulfilled this function. Additional information related to this analysis question can be found in the interviews at the end of the course in which I asked students specifically about their recognition of the main thread. From these interviews (that will not be further reported) it became clear that most students were unable to explain why they did the bit on mechanicism. Only two students could say something correct about mechanicism. Expectations of what they will be learning later on in the regular course on mechanics were vague and uncertain. Students therefore did not arrive at a notion of mechanics as being far ranging or having great scope. This did not hinge on appreciating the mechanicism argument (although this also contributed), but is an effect of continually failing to make the main thread clear enough to be recognised. When students do not really know what mechanics is all about it is hard to appreciate its power and range.

25. Students considered the asteroid problem solved, when asked[10] in the interview concerning the recognition of the main thread at the end of the course. All students considered that the implicit promise at the beginning of the course that at the end of the course the asteroid problem would have been solved was met. None felt cheated in this respect. All students except one had the idea (justified or not) that they were able in principle to calculate whether the asteroid would hit the earth or not.

Suggestions for improvement

The additional feature of the computer model of the asteroid, it allowed changing the initial values for the position and velocity of the asteroid and earth, needs more explicit introduction when retained or can be skipped altogether. Its function was to show that a collision depends entirely on such starting values. In retrospect the function of the asteroid problem at this stage is merely to show that it can be solved with a proper model, for which varying initial values is not essential.

The mechanicism account did not function as expected. It is hard to say whether it would have functioned when it would have been executed as intended. I think it is weak even in a proper execution. Although it shows how some macroscopic phenomenon can be explained and understood in terms of moving and interacting particles, it does not show how actually calculating the motion of these particles adds up to a macroscopic phenomenon. The point that since particles are moving, mechanics would be applicable and therefore important glosses over the question how mechanics would help understanding/explaining/predicting the phenomenon. Calculating the motion of sugar and tea particles does not help in any way to understand better the common phenomenon of dissolution of sugar in tea. I am afraid that another example which actually shows how microscopic calculations add up to some macroscopic phenomenon will be too difficult.

[10] Without such a question I think none would have remembered that such an implicit promise had been made.

6.4. Conclusion main theme 3

Before drawing some conclusions concerning main theme 3 as a whole I will summarise the answers to the analysis questions related to the various episodes in the following table, see Table 3.

Main theme 3: Evaluation of models and *types of model* in the light of achieving broader applicability.		
Function of main theme: Both a reflection on criteria to determine which type of model explains best and subsequent application of these criteria should result in an appreciation of Newtonian models and an outlook on the regular course.		
Episode	Analysis Questions	Answers
3.1 Reflection on types of model	19. Do the criteria for valuing models and types of model surface clearly? 20. Does a strategy for further investigation surface naturally?	No. Although implicit use has been made of the criteria plausibility an empirical adequacy, this use was not made explicit. No, it did not surface at all, but it might have.
3.2 Introduction to a choice between types of model for a situation on earth	21. Can students give reasons to value N above K? 22. Do students see the reason for applying K and N to a situation on earth? 23. Does the application of K recognisably (for the students) lead to problems?	No. Some intended criteria for valuing models were used, but these were not highlighted and explicitly discussed and therefore did not function clearly enough as a basis for a reason for preferring Newton to Kepler. No. In the interviews at the end of the course none could explain why the transition to situations on earth had taken place. No.
3.3 Asteroid problem, mechanicism and transition to the regular course	24. Do they have some impression of the power and range of Newtonian models? 25. Do they consider the asteroid problem solved?	Very little. Students did not arrive at a notion of mechanics as being far ranging or having great scope. This is an effect of continually failing to make the main thread clear enough to be recognised. When students do not really know what mechanics is all about it is hard to appreciate its power and range. Yes.

Table 3: Summary of answers to analysis questions of main theme 3

Criteria to determine which type of models explains best can be used and were used, but should be made more explicit, especially ‘broad applicability’.

Appreciation of Newtonian models can be expected to be better when the main thread is more used and explicated. Now the design suffers from cumulative effects of earlier failures in main theme 1 and 2. The mechanicism part seems now not very strong.

An outlook on the regular course has hardly been achieved. Such an outlook would have been provided by a clear perspective on the main thread of ‘this is mechanics’, which was now lacking.

7. Choices for interaction structures

The recurrent phenomenon in the episodes was that an important question to answer in the analysis of each episode, namely whether the choice for the used interaction structure was good, was difficult to answer. The difficulty lays in the fact that most episodes were not executed as intended mainly in respect to the interaction (an exception was episode 1.4 that went largely according to plan). Usually the main activity went all right, but was not properly introduced and evaluated. Since the difference between the used interaction structures mainly lay in the evaluation part, it became very hard to find any empirical backing for the choices that were made. What *could* be seen sometimes was that an evaluation might have taken place as intended given the kind of student input from the main activity (examples are episode 1.1, 1.2, 1.5, 2.3 and 3.1). These instances then provided a minor empirical backing for the choice of interaction structure. Although showing that an evaluation could be given in close connection to student input suggested that the students would have understood such an evaluation, this was not tested and therefore remains to be seen. On the other hand, the experiences with the scenario did not invalidate the arguments for the choices of interaction structures given in the scenario. This part of the design therefore remains largely hypothetical, in the sense that arguments for particular interaction structures are based on ideas instead of empirical findings.

8. Embedding in the regular mechanics course

The fourth main theme, embedding in the regular course, concerns the directions and guidance given for the regular course as was written down in the link-manual.

The experiences with the link-manual came from two sources. Firstly, the second teacher reported some experiences in an interview I held with him during the regular course. Secondly, students were interviewed during the regular course in which they were asked whether they recognised elements of the introductory course in the regular course. Furthermore they were asked to solve some textbook problems that were selected to trigger possible use of elements of the introductory course. I will subsequently discuss these two kinds of experiences with the link-manual.

Experiences reported by the teacher

Unfortunately the experiences with the link-manuals after both introductory courses are very limited. The teachers did not use them, which is probably due to the advisory nature of both the link-manual itself and the introduction of the manual during the teacher preparation. Both were largely in the form of suggestions for adaptations of the regular course. This way of presenting left the teachers a lot of room for ignoring it. The second teacher reported some ‘natural’ use of the explanatory scheme for motion that was mainly instigated by himself without use of the link-manual and then recognised by the students. He gave the examples of two falling objects of different mass and a vertically moving pellet shot from a horizontal moving cart (observed using a photograph and a stroboscope), which, he noticed, could be quite naturally explained by him using the concept of influence free motion after which he observed an 'aha-erlebnis' in students. Another idea that the teacher claimed was now better understood was that absence of force not necessarily implies rest. Furthermore he encountered no difficulties in the transition in language from laziness to mass and from influence to force et cetera. He also mentioned the more general perspective on mechanics.

A positive side-effect of the way of working during the course that still lingered in the regular course was that students did stick to a cooperative way of working that emphasised understanding, according to the teacher.

Some time after this interview the second teacher expressed some disappointment about how little spontaneous transfer could be noticed. The fact that he expected spontaneous transfer indicates that something went seriously wrong in my presentation of the link-manual to him. Apparently the whole basis on which this document was built, i.e. the tenet that specific effort has to be made to show and use the connections between introductory and regular course had not been convincing or had not come across. A discussion of my preparation of the teachers took place in section 3 of chapter 4 and also section 3 of this chapter.

Experiences from student interviews

I will first describe the method and design of these interviews and then the results.

Method

During the regular course interviews were held with students to see to what extent the introductory course was useful in discussing (conceptual) mechanics problems. How do students reason with these problems? Do they use elements of the course or recognise them when they are used by the interviewer, like the explanatory scheme for motion? Useful instances of possible application of the introductory course are questions that trigger the usual learning difficulties encountered in mechanics for which this course aimed to provide some means of addressing them. In these interviews students were therefore presented with such questions. When students could discuss these questions with each other and with the interviewer, this was expected to provide information for the research question of this interview of how students reason with these problems and, as part of that question, whether they use elements of the course or recognise them when they are used by the interviewer.

Questions that were used in these interviews were obtained from the well known FCI, mentioned in chapter 2, because use of FCI items has the advantage that the common opinion seems to agree that these questions really concern the classic learning difficulties in mechanics. A meaningful discussion of these questions can therefore be more convincing than a similar discussion of questions I cooked up myself. In the latter case I would have to provide some arguments for that the question triggers some conceptual problem, which can in principle be done, but in practice is less efficient than using what is already available. A discussion of all answer alternatives (instead of merely selecting one from the multiple choice alternatives) could show the reasoning behind the choice and could therefore allow some use of the introductory course to become visible. Pointing out why some alternatives are wrong from the Newtonian perspective is just as interesting and informative as pointing out why one alternative is right. I therefore retained the original multiple choice alternatives, but let students discuss all alternatives. Four interviews were held with the total of eight students that participated in the second trial: two pairs, one group of three students and one single student.

Not all FCI items were relevant for my purposes. For instance many items can hardly be answered with knowledge from the introductory course. The selection of relevant questions happened in the following way: All FCI items were analysed using the conceptual material of the introductory course, each time starting from first principles.

Take for example the first FCI item:

> 1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:
>
> (A) about half as long for the heavier ball.
>
> (B) about half as long for the lighter ball.
>
> (C) about the same time for both balls.
>
> (D) considerably less for the heavier ball, but not necessarily half as long.
>
> (E) considerably less for the lighter ball, but not necessarily half as long.

To answer this question from first principles using the introductory course would result in a very complex argument like the following:

> The influences working on the ball are gravity and air friction. The air friction on a metal ball is probably negligible compared to gravity. Gravity on the ball is proportional to its heaviness. The deviation from the influence free motion that is generated each time step by gravity is therefore proportional to heaviness/laziness. When we assume that heaviness equals laziness (and equals mass), then the deviation from the influence free motion generated each time step by gravity would be the same for both balls. Since both balls start from the same height from rest, they will in fact both move in the same way. They will therefore reach the ground simultaneously and almost simultaneously when air friction is taken into account. The answer is therefore alternative C.

This question is in theory answerable using the introductory course and therefore one might think that students can be expected to fare slightly better on this question after a successfully designed and executed introductory course, than without such an introduction. However, since the argument for arriving at the answer is very complex this expectation is more likely to shrivel to unnoticeable size.

All FCI items were analysed in this way which resulted in expectations about which questions students would answer better after the introductory course. A more complex argument, as the one seen above, generally indicated that little improvement could be expected. For more simple ones more improvement could be expected. This resulted in a subset of FCI questions that are relevant for this course and that contain the questions 5, 8, 10, 18, 22, 27, 28 and when the optional episode 2.5 is part of the course also questions 6, 24 and 26, see appendix I. These questions were discussed in the interviews. Recurrent guiding questions in the identification of forces that the interviewer posed were related to the two aspects of mechanics: the relation influence – motion and a plausible interaction theory. The former can be expressed as ‘why does the identified force have to be working?’. The latter can be expressed as ‘where does the force come from?’ From the interviews themes were identified around recurrent topics like frequently used arguments, the kinds of non-Newtonian notions that surface or particular successful or unsuccessful ways of addressing these notions.

Results from these interviews

I identified recurrent notions from the interviews that were held and grouped these into themes. Some of these themes I like to discuss here, for they contain some clues how students reason, the kind of arguments they use and how this reasoning might be corrected (that is modified in a more Newtonian way of reasoning) in a way that makes sense to them. Two of these themes concern two typical non-Newtonian notions that were triggered in the students by the questions. In the discussion of these notions two typical arguments were used to identify forces. A seemingly successful way of using elements of the introductory course to address these non-Newtonian notions made use of the graphical construction method.

I will now give an account of these two non-Newtonian notions, the two typical arguments and the way of addressing, illustrated with quite a lot of fragments to give the reader a feel for the way students talked about explaining motions. These examples were selected to illustrate these themes as clearly as possible. Although with four interviews and seven students it is somewhat ridiculous to talk about *typical* examples, the following examples do indicate features common to more than one student.

One non-Newtonian notion that occurred time and again is the Keplerian notion that (larger) speed is accompanied by (larger) force. Take for example a response to FCI item 5 concerning the identification of forces working on a vertically thrown object:

1. I: […]. If you had to choose between these, what would you choose?
2. Ros: Between B and C?
3. I: Yes.
4. Ros: I’d choose B.
5. I: Why?
6. Ros: Because here ehm, let’s say constant, at C it goes constant down, that ball?
7. I: No, It says a constant gravity
8. Ros: But with that gravity they just mean how fast it goes down, don’t they?
9. I: No, with gravity they mean a Newtonian influence, named gravity.
10. Ros: (Then I don’t know what).

Rosa seems to equate gravity with ‘how fast it goes down’ (8).

Another recurrent non-Newtonian notion is the idea of a force having an aftereffect. Take for example the following response to FCI item 27 concerning the speed of a rocket after its engine has been turned off at point c.

1. I: After c there is no influence any longer, is there?
2. Jol: No, I know that. But first, that it will go faster after that by the influence before c.
3. I: Hm hm.

4. Jol: But then it could not.
5. I: I don't understand it completely.
6. Jol: No, because look. Yes. Before point c, than there is an influence. Then after after point c …[audio tape ends]
7. I: Okay. No allright. But your idea would be that it in fact after c, that the influence in a way still works…
8. Jol: Yes.
9. I: … (then) goes somewhat faster. And after that moves constantly. Yes?
10. Jol: Yes.

Jolien specifically mentions that she is aware that the initial influence had ceased (1, 2). However, she still attributes some lingering effect of this influence after it had ceased (6). Jolien assents to my interpretation of this as an aftereffect in (7, 8).

The recurrence of non-Newtonian notions such as these need not be surprising. I did not expect the introductory course, even an improved and well executed one, to make students into Newtonian thinkers. I am therefore not in the least bit concerned that notions such as the two presented surfaced. What is interesting is how these notions are discussed. It is precisely in discussing such notions that the introductory course may show some effect, and it was for this reason (checking whether such an effect can be seen) that these interviews were held.

How were these kinds of problem discussed? Two elements that were frequently used in the discussions by the students (and interviewer) when identifying influences were the arguments from interaction theory ('where does the force come from?') and from the relation force – motion ('why does the identified force have to be working?'). The following examples show how these arguments were used:

The argument from the relation force – motion:

1. Jol: Yes, I think that the gravity remains constant, for the ball is not thrown that high. So, I don't think that gravity increases or decreases.
2. I: Okay. But gravity has to be there, according to you.
3. Jol: Yes.
4. I: Why?
5. Jol: Otherwise it would keep floating.

The influence has to be present because otherwise the motion would be different. The following example shows a more elaborate use of the same argument:

1. Chr: Yeah. (There are of course) motion (…) Something has to have some effect. There has to be some force that has some effect.
2. I: Hm hm. Why is that?
3. Chr: Well, because when you throw the ball upward, it will move upward slower and slower. And after some time it will fall down. It will go increasingly faster downward, so there has to be something that causes that faster and slower.

There has to be something, i.e. an influence, that causes the acceleration. Here again the motion dictates the presence of an influence.

The argument from interaction theory is illustrated in the following response to FCI item 5:

1. I: Okay. We are in doubt about B. 'A steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.'
2. Car: That is wrong, according to me, because it would be (strange) when from that point onwards, is the downward gravity, and that one is there all the time, I say.
3. Mer: The gravity is not continually increasing, is it?

The identification of a non-constant (in fact suddenly appearing) influence is rejected based on knowledge of how gravity roughly works (namely all the time and constant close to the earth's surface), i.e. a rough interaction theory. Another example of the same type of argument is the following response to FCI item 10 concerning the motion of a ball leaving a circular channel with a gap.

> Jol: Well, I think B because here it [the ball; ASW] is pushed by the channel in that direction, and here the channel is no longer present, so there is no more influence left.

The channel is the influencer. When the channel ends, its influence can no longer work on the ball. Both arguments surface in the following discussion of the same FCI item. Alternative A and C both indicate curved trajectories:

1. I: Yes. Okay. What would you say about this [A or C] response?
2. Ros: Yes, that could be, but it has to be influenced a little bit…
3. Jol: Move the other way.
4. I: Yes, and where would that influence come from?
5. Jol: From the table surface or something.
6. Ros: (…)
7. I: Yes, okay, so but that is not the case here.
8. Ros: No, than it would move straight on.

First the need for an influence is expressed (2) based on the motion. Secondly these alternatives are rejected based on the absence of a feasible source of such an influence (7), which might have been the table surface, but this possibility is not considered likely given the expression 'or something' (5) and Rosa's assent to my rejection of this possibility (8).

So students made use of both the argument from interaction theory and the argument from the relation force - motion. The latter only leads to Newtonian explanations when the relation between force and motion is well understood. For discussing non-Newtonian notions it seemed useful to recall elements from the introductory course amongst which the graphical construction method. The following two examples illustrate the importance of connecting to the introductory course. The first illustrates an unsuccessful way of addressing the non-Newtonian notion of 'no force implies no motion', which can be seen as a special case of the '(larger) speed is accompanied by (larger) force' notion. It is my claim that it is unsuccessful because it does not make use of the introductory course. The second example illustrates a way that seems more promising. After these two examples I will turn to how the graphical method may be used in discussing these non-Newtonian notions.

In response to FCI item 18 about comparing the sizes of the forces working on a constantly upward moving elevator:

1. Ros: If there would not be any influence, the elevator would not move upwards, would it?
2. I: Well, according to Newton it would.
3. Ros: But in that case it would move down, wouldn't it?
4. I: No. Look it is true. Look, when the elevator is not moving, let's say it is standing on the ground. If you want it to go up, than you would need a short net influence upwards. Than it would accellerate upwards. When it is at some particular height, so it has been put into motion, and I want it to continue moving with constant speed, then I would need a net influence of zero. There is gravity working, pulling it down all the time. When I compensate that with an equal force from the cable in the other direction, making the net result zero, than it would move here with constant speed according to Newton.
5. Ros: So B.
6. I: So B. But do you find this a convincing story?
7. Jol: Yes.
8. I: Ha ha ha, yes, you are saying yes, but you do not sound very convinced, ha ha ha.
9. Jol: Yes.
10. I: Okay. Rosa isn't.
11. Ros: Yes, it sounds quite logical. Ehm, it looks quite logical and stuff, but I would, one has to have some experience of sorts, when one believes it to be, sounds quite logical.
12. I: Yes, but the whole problem is that one cannot experience this.
13. Ros: No, yes that's why. So you have to believe what is being said.

My explanation (4) was not coming across, which I noticed at that time (8). Jolien who was on the whole much closer in her reasoning to the Newtonian approach disagrees. She claimed she did understand it (7). Rosa cannot relate this explanation to her experience and has to accept it on faith (11, 13), although she said that it sounded logical.

The explanation in the following example from FCI item 5 (vertically thrown object) about the difference between speed and force seems more promising

1. I: […]. So here was an influence from the hand, …
2. Nic: which causes its speed.
3. I: …which causes its speed …
4. Nic: And after a while that influence is not working any longer and then it will go (…).
5. I: Well, this influence is no longer working the moment the pen leaves my hand. Then I no longer influence it.
6. Nic: Yes, but (…)
7. I: Yes, but not according to Newton …
8. Nic: No.
9. Car: No.
10. I: He says: no, I do not need that, for what I assume is that it has received speed. According to me when something has got speed and no influence is working,

it would simply continue. With a constant speed it would continue to fly higher and higher. Well, that is what happens.

11. Car: A kind of influence free motion.

The first example did not really use any elements from the introductory course. The unsuccessful explanation given here by me could have been given by any teacher unaware of the introductory course who would try to remedy this particular notion. The second example did make use of some elements of the introductory course: It recalled the perspective with which these questions are answered, namely the Newtonian one (7, 10), which triggered a recollection of the notion of influence free motion (11).

Another element from the introductory course not used in these examples, uses the tool of graphical constructions to discuss the relation force - motion. Although students did not use the graphical method spontaneously, they were able to understand and be convinced by an account given by me using this method.

Two more observations in connection to these interviews are that: (1) In general can be said that students were very willing to discuss different explanations of motions and could use good arguments (or at least recognise them when they were given) in these discussions. The theoretical orientation of wanting to really understand some motion (most of which were completely irrelevant from a practical point of view) had been properly established. (2) The usefulness of the Newtonian approach as a powerful way of explaining motions that is therefore quite naturally adopted when asked to explain motions has not become established to the intended degree. Given the experiences with the second trial this is not that surprising, but an improved version of the design should result in the clear conclusion that Newton is the winner.

Conclusion from these interviews

In reasoning about explanations of motion elements from the introductory course can be used productively: arguments for identifying influences from relation influence – motion and from interaction theory are already used by students, the graphical construction method is not used by them, but can be recognised and understood and can be convincing, recalling Newtonian (or Keplerian) perspectives immediately trigger a proper mindset of theoretical explanations and bring to mind specific details of their theories.

Reflecting on the usefulness of the graphical method I think that such constructions are really needed to address the difficult topic of conflict between the argument from motion and the argument from interaction theory. Usually with the kind of (FCI) problems that were used, wrong answer alternatives can be dismissed because the depicted motion calls for some influence, mostly in the direction of motion, based on the argument from motion that can not be there because of the argument from interaction. For this reasoning to be convincing one should see how the influence that *can* be identified (e.g. only gravity) can account for the complete motion (e.g. vertical toss). The reason many students identify some upward force is that they very strongly feel the need for one because of the argument from motion. Countering this argument only with the argument that the force of the throw cannot be working after the throw many students find insufficient. For this second argument to be convincing quite an elaborate Newtonian interaction theory is already required. An alternative approach would be to use the first argument and show how the same motion can be accounted for without identifying the non-Newtonian force. This approach uses the graphical construction method.

Further research

What this section has shown so far is that making use of the introductory course in the regular course is important and needs to be carefully developed. The preliminary attempts made here suggest some promising ways in which this topic can be further developed, but much more thought and trial is required to arrive at a proper approach for the regular course (e.g. written down in a link-manual) that optimally uses the introductory course to productively discuss the usual mechanics problems. Looking back the amount of work (and time) involved in this aspect of my research had been underestimated.

9. Concluding remarks

In this chapter the results of my design have been presented on a detailed level. The method for data collection, analysis and presentation was described in section 2. Here was seen that the scenario and the analysis questions guided a way through the plethora of collected data of which only a small fraction could be displayed in this chapter.

In section 3 the results of the teacher preparation were presented. The picture that arose there was that given the restrictions in time the teacher was prepared as best as I could manage, although the idea of using interaction structures as a tool for the teacher in designing a practical implementation of the already designed content was not fully accepted.

The sections 4, 5 and 6 contained the detailed results of main theme 1, 2 and 3 respectively. The first main theme, the how and why of explaining motions, resulted in some empirical backing for the ideas for triggering and explicating both the general explanatory scheme and the explanatory scheme for motion. The asteroid problem and the general explanatory scheme as stepping-stone might also perform their intended functions and students were seen to develop some sense of theoretical orientation. Other important goals were not achieved: Students did not see the explanatory scheme for motion as a special case of the general explanatory scheme and they did not realise that for a complete explanation of motion further specification of the elements of the explanatory scheme would be necessary. These failures here, as well as in the other themes, were mainly attributed to deviations in the execution. Apart from the few scenario improvements that had been suggested in the course of section 4, this test did not provide empirical grounds for changing the design of main theme 1 in a major way.

The second main theme, the extension of knowledge by detailing the explanatory scheme to arrive at empirically adequate models for explaining planetary motion, resulted in disappointing recognition of the main thread and poor understanding of the mechanics content by the students. Students did manage to use the criteria of empirical adequacy and plausibility for choosing between models. Both Keplerian and Newtonian models remained feasible alternatives.

The third main theme, evaluation of models and *types* of model in the light of achieving broader applicability, resulted in the observation that criteria to determine which type of model explains best could be used and were used, but should be made more explicit, especially ‘broad applicability’. Furthermore, cumulative effects of earlier failures in main theme 1 and 2 made the appreciation of Newtonian models rather weak.

In all main themes little could be said about the choice for the used interaction structures.

The fourth main theme, embedding in the regular course, was approached differently than the other main themes. It was investigated to a far less extent than the earlier main themes and merits further research. However, some preliminary findings that I came across include that in reasoning about explanations of motion elements from the introductory course could be used productively. Arguments for identifying influences from the relation influence – motion and from interaction theory were used by students themselves, the graphical construction method was not used by them, but could be recognised and understood and provided for convincing reasoning.