

Chapter 7

Reflection

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1. Introduction

In this chapter I will look back on the starting points of this research in light of the results. The starting points were the educational goals, my problem analysis, approach to overcome the identified problem in learning mechanics and my view on teaching/learning. In section 2 will be discussed to what extent the educational goals have been reached and whether they can be reached. The evaluation of the other three starting points in section 3 amounts to a discussion of the idea of using the explanatory scheme in a problem posing way. In that section I will reflect on this idea and describe two main problems I encountered in putting this idea into practice. In section 4 I will argue that these problems can not be easily solved by applying advice from the research literature, but that this literature may trigger some useful further thought about possible directions in which solutions may be found. Finally, in section 5, I will present some ideas for addressing the main problems in the design. These ideas are naturally not worked out in great extent and will require further research to prove (un)workable.

2. Are the goals met?

The three main educational goals of the introductory course were (see chapter 3 section 1) that students (1) come to know how mechanics works, (2) develop some appreciation for its power and range and (3) acquire a vocabulary with which the usual learning difficulties can be discussed. Of course this did not mean that students should understand mechanics after only an introductory course. With ‘knowing how mechanics works’ was meant some insight in the broad picture of the project of doing mechanics, that is knowing *that* the central concepts of influence or force, laziness or inertia, influence law or force law, et cetera are related and account for motion, and have some sense of *how* they are related and account for motion.

The second goal of appreciation for the power and range of mechanics meant having some sense that Newtonian mechanics is (1) quite good in predicting and explaining motion, (2) quite plausibly and (3) in a quite general way. In here the three criteria of empirical adequacy, plausibility and broad applicability can be recognised. The vocabulary useful for addressing learning difficulties would then consist of the mentioned main concepts of mechanics like influence, influence free motion, laziness et cetera and their more widely used counterparts in regular mechanics.

To what extent have these goals been reached? And can they be reached? I will subsequently discuss these questions for each of the three goals.

Know how mechanics works

To what extent the goals of each episode have been reached was described in detail in chapter 6. There was seen that students had difficulty distinguishing influence from parameters in an influence law. Furthermore they had difficulty relating influence, laziness and deviation from the influence free motion in the intended way, that is, in accordance with the rule $\text{deviation} = \text{influence}/\text{laziness}$. Instead they related influence

and laziness to the more readily observable effects on the motion in the explored computer models, which I called an operational understanding (see chapter 6, section 5.3).

Looking more closely to what students were meant to do to construct the concepts of laziness and influence, one can find a possible explanation for this difficulty. Students were expected to get some sense of what laziness is by a single example, namely varying the laziness of a planet moving around the sun in a computer model. Furthermore the notion of laziness could very easily be confused with the earlier explored effect of influence on the planet (also using a single example), since both concepts had similar results in changing the motion of the investigated planet in the computer model. Although at the time this seemed to me quite doable for students, I now think that establishing the main concepts in mechanics like laziness or influence in relation to each other is more difficult than expected.

One possible approach to overcome this difficulty is that one could reconsider the introduction of the various concepts in an introductory course. Omitting laziness, for instance, would considerably reduce the number of relations between the concepts. The concept laziness was needed in this introductory course for making the Keplerian type of model a feasible alternative to the Newtonian type of model when modelling more than one planet. Can this be achieved without introducing the concept of laziness (in an introductory course), but such that there remains a sufficient basis for evaluating the relative merits of Keplerian and Newtonian models as applied to the motions of the planets? Further research may shed more light on if, and how, this is possible.

The results of thirteen 65' lessons (approximately seventeen 50' lessons, about the same amount of time spent in a regular course on Newton's laws) may seem somewhat meagre. Even when one takes into account that the introductory course also aims at other goals and is still in the experimental phase. It can be expected to be shortened after some streamlining. This first goal is largely addressed in the first two main themes which took nine 65' lessons. Some minor adjustments like skipping the detailed and optional graphical construction method and cutting some corners would still result in about six 65' lessons (about eight 50' lessons). This is still a considerable amount of time to spend on only an introduction. Far from suggesting that such an introduction is better omitted, this further indicates the difficulty in arriving at the regular educational goals for mechanics that, as was mentioned in chapter 2, are not met in traditional education. The point I am making here is that knowing what mechanics is about as an educational goal of any regular course (preceded or not by the designed introductory course) may be more difficult to achieve and more time consuming than even people who are aware of the learning difficulties in mechanics anticipate. My assumption has been all the time that the regular educational goals for mechanics are attainable in principle, given some properly designed and executed course. This does not mean, however, that these goals must be attainable in roughly the same amount of time as is normally spent on mechanics in traditional education (which results in not attaining these goals).

Appreciation of power and range

Appreciation of the power and range of (Newtonian) mechanics was lacking although students were seen to implicitly apply the epistemic virtues. This leads me to believe that when these criteria are made explicit and used as such, students would be able to give some argued reasons for preferring Newtonian mechanics, which would amount to some appreciation. This goal builds on the previous one, since knowing that Newtonian mechanics is empirically adequate and broadly applicable without some sense of how the main concepts are related and therefore without knowing what Newtonian mechanics *is*, is not much of an appreciation¹.

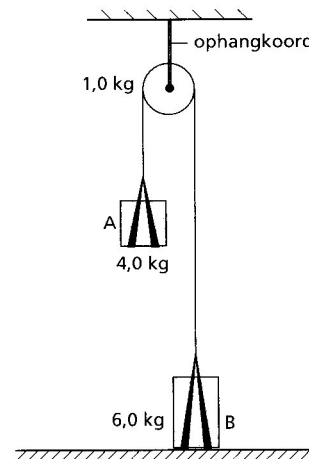
Vocabulary

The vocabulary in which to address the usual learning difficulties would have to use notions like influence(law) and laziness (or their more widely used counterparts), which had not become sufficiently clear for this purpose. Students' weak grasp of such concepts makes a convincing discussion of these problems very difficult. In chapter 6 also some encouraging aspects were found in a preliminary attempt at discussing several triggered learning difficulties during the regular course (see chapter 6, section 8). Students made use of two specific arguments, the argument from interaction theory, which can be expressed as an answer to the question 'where does the force come from?', and the argument from the relation force – motion, which can be expressed as an answer to the question 'why does the identified force have to be working?' Both questions need to be answered in almost all mechanics problems, but are seldom explicitly asked. When these basic arguments can be combined with a sufficient understanding of the main concepts, one has obtained a useful approach for addressing most of the mechanics problems.

Many problems neglect the interaction theory aspect. Take for example the kind of reasoning expected in the following question, obtained from a much used physics textbook for the fourth grade (16 year old students):

See Figure 3.30. The mass of the cords is negligible in comparison to the mass of the blocks A and B.

- Redraw this figure and add to your drawing the forces working on A and those working on B.
- Which block needs to be considered first in order to calculate all these forces?
- Now calculate these forces.



¹ Finding Newtonian mechanics more plausible already implies some understanding of its main concepts. Plausibility differs in this respect from the other two criteria.

The causal chain of events in this example is that various ‘influencers’ work on the object in question by applying some force. (How they do this is part of the interaction theory aspect). These various forces add up to one net force. This net force causes a deviation from the influence free motion and therefore accounts for the observed or predicted motion of the object (the relation force - motion). In this example and many others this chain of events is assumed to be clear. Students are then asked to reverse this reasoning by determining some force from the motion of the object, which in this case is rather easy, namely rest, but in many cases is motion with constant velocity. Since two of the forces adding up to the net force are clear from grounds of interaction theory (gravity and the force in the rope), another force that is also part of the net force, the normal force from the ground, can be calculated. The question where that other force comes from (interaction theory) is not addressed and of course one does not have to, strictly speaking. However, not addressing it assumes a lot of trust in and familiarity with the whole line of reasoning. I think using the two mentioned questions when discussing mechanics problems can make a lot of the steps in this kind of reasoning explicit and thereby clarify some confusion.

3. Are the starting points still useful in meeting the goals?

Apart from the educational goals mentioned in the previous section there were three more starting points in this research: My problem analysis, approach to overcome the identified problem in learning mechanics and my view on teaching/learning. These starting points amounted to the ideas (1) that common sense and Newtonian mechanics have an explanatory scheme in common and (2) that this commonality could be used in teaching/learning mechanics in a problem posing way. In this section I will reflect on especially the second idea and describe two main problems I encountered in putting it into practice.

Putting it into practice involved that the explanatory scheme, after being triggered and explicated, was to guide students in a process of further specification of the scheme leading to a first encounter with the main Newtonian concepts like influence or force, laziness or inertia, and heaviness or heavy mass, and their relation to motion. Furthermore the difference between common sense and Newtonian ways of explaining motion was attributed to various ways in which one can specify the explanatory scheme, reflecting one’s aims and interests for such an explanation. Within those specifications that are more theoretically oriented, like those of Kepler and Newton, the epistemic virtues of empirical adequacy, broad applicability and plausibility become more important². They can function as criteria for comparing and weighing alternative theories and can thereby also help guiding the teaching/learning process. The guidance provided by the explanatory scheme and epistemic virtues would consist of giving students some perspective on what they are doing and why, and thereby aid in making the approach problem posing.

² There are also other epistemic virtues, see e.g. (Quine, 1966), but these three played a part in my design.

There are no reasons to doubt the notion that common sense and Newtonian mechanics have an explanatory scheme in common, which will therefore not be further discussed. This aspect of the problem analysis is still valid. The suspicion that this commonality could be used in teaching/learning mechanics in a problem posing way, thereby reaching certain educational goals, however, raises some questions. To what extent can the goals be reached? And can the design be said to be sufficiently problem posing? The first question has already been addressed in the previous section. In answering the second question let us revisit the didactical structure of the design, for it makes explicit the succession and interplay of activities and motives and shows therefore its problem posing character on a structural level. After that I will reflect on how this didactical structure was implemented in the teaching/learning activities, which shows the design's problem posing character on a more detailed level.

Didactical structure

The didactical structure of the design is depicted in Figure 1 in chapter 5. The course started with a broad orientation on motions that are worth predicting or explaining. This orientation concerned both learning about mechanics (the left column in Figure 1) and learning about explaining (the right column). I have found no indications to doubt that the asteroid problem is a good example in this respect.

This orientation resulted in the notion that this could be an important and interesting theme worth knowing more about. This notion then functioned as a motive for starting with exploring explanation in general and explanation of motions in particular. Students were seen to make use of the explanatory scheme, but this use was not explicated, so that students remained unaware of this use. This did therefore not sufficiently lead to the feeling that it is a theoretical challenge to explain motions by means of an as yet unknown specification of this underlying scheme. Although students did develop a theoretical orientation to the extent that they understood the goal of 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, they did not come to realise that for a complete explanation of motion further specification of the elements of the explanatory scheme would be necessary. This crucial motive for engaging in learning most of the mechanics content in the next step was lacking.

The main thread in learning the mechanics content was that it was organised as a step by step specification of the underlying explanatory scheme for motion into two specific schemes (Keplerian and Newtonian) in the context of developing and testing models of the motion of heavenly bodies. This thread was not recognised at the start of this part of the course (as a motive), and was not picked up during the subsequent unfolding of the course either. Since the course design made the explication of the explanatory scheme an essential prerequisite for learning the mechanics content, this problem of explicating the scheme is one of the main problems in the design.

In chapter 6 the failure in explicating the explanatory scheme for motion was mainly attributed to the deviations in the execution of the scenario. There were no empirical findings that suggested major changes in the design of the first main theme. However, in this chapter I would like to further qualify this conclusion by suggesting some other ways in which the design may be improved than those already mentioned in chapter 6,

triggered by research literature I became aware of after identifying problems in my design, see section 5 in this chapter.

Although learning results of the mechanics content proved to be unsatisfactory, the extensive exploration of the Keplerian and Newtonian specifications of the explanatory scheme did result in raising the motive of evaluating the fruitfulness of the specific schemes and models, which prepared for a reflection on criteria to determine which schemes and models explain best. In the reflection the intended criteria for choosing between types of model did surface, but were not made explicit. Therefore, the criteria could not be seen to function in motivating a plan for further validation of the specified schemes, namely the application of Keplerian and Newtonian schemes to motions on earth. After this the cumulative effects of the previous shortcomings makes claims about the rest of the (didactical structure of the) design speculative.

For the sake of completeness I will risk a few speculative remarks about the final steps in the didactical structure. The intended reason for exploring motions on earth was that application of the criterion of broad applicability might help in the evaluation of the two alternative types of model. This was not understood. This made surfacing of the next motive, which is the closing question “which schemes and models explain best?” and its answer in the final evaluation of which schemes and models explain best and which elements of this scheme are still unknown very difficult. With a shaky grasp of what mechanics is all about and lacking *explicit* criteria for choosing between different types of model an appreciation of the Newtonian scheme by students can no longer be expected.

In conclusion: The main (structural) problem is the unsatisfactory explication of the explanatory scheme, and thus the failure to provide a proper motive for engaging in learning most of the mechanics content. The other motives in the didactical structure seem to function more or less as intended, although this claim for the final steps is rather speculative. On this structural level the design can be said to be sufficiently problem posing, except for the mentioned problem.

Implementing the didactical structure in the activities

Although on the structural level the design seems to be quite alright, apart from the mentioned problem, on a more detailed level the design still falls short in implementing this structure in the activities within the episodes. The intended motives were not sufficiently incorporated in the design of the successive activities. In retrospect one can see this already in the description of the design. The reason that some activities could not become ‘alive’ in the sense of forming a driving force behind students’ learning is that many a time such reasons were meant to be told by the teacher, instead of arising more naturally from students themselves. Although it was at these times intended that the teacher would only have to make some reason explicit based on student input that was triggered in some preceding activity, or recalling such motives in an introduction of the current activity, these kind of evaluations and introductions would be better designed if they involved more student activity.

To name but one example, in episode 2.5 about the precise relation between influence and motion, students were meant to develop some trust in the difficult graphical

construction technique by exercising it in a couple of assignments (see chapter 5 section 4.5). They were seen to get lost in the details and had no idea what they were doing at that time (see chapter 6 section 5.5). The designed questions did not provide students with a motive for engaging in the activities that was recognisable and ‘driving’ enough. There was a motive in the design, but this was intended to be expressed in the introduction of these questions by the teacher, which involved students only to the extent that they had to listen to some exposition³. It would be preferable when such important aspects as raising a motive would involve more student activity than only listening. It is therefore understandable that they were rather lost in this case.

My primary intention was to design a course bottom-up, meaning starting from common sense and continually using what students bring in (see also chapter 3, section 4.1 where my view on teaching/learning was described). However, in retrospect much of the design turned out to be too much top-down, in the sense of emphasising teacher input, such as in the mentioned example. The activities exhibited too much of a kind of ‘transfer’ perspective on teaching/learning, and too little of the intended educational constructivist perspective. As a result the designed activities did not guarantee that student input would matter⁴, which I consider an important ingredient of a more constructivist educational design. So the design being too much top-down is in contrast with the intention of making student input matter, as well as attributing to not rightly implementing motives.

4. Some aid from the literature?

The main problems in the design that were described in section 3 lay in explicating the explanatory scheme and implementing the didactical structure in the activities in a bottom-up way. Furthermore there were the earlier mentioned problems in the execution of the design, which were related to difficulties in the design itself and difficulties in the teacher preparation.

In this section I aim to show that these problems can not be easily solved by applying advice from the research literature, but that this literature may trigger some useful further thought about possible directions in which solutions may be found. This may also make the difficulties themselves somewhat clearer.

4.1. Explicating the explanatory scheme

The difficulty in explicating the explanatory scheme may lie in that it makes explicit a high level of causal thinking. It could be the case that this causal thinking in itself may be more difficult than anticipated. Making it explicit would then also prove to be more difficult than expected. What has the research have to say about the difficulty of causal

³ When the teacher succeeds in recognisably using a lot of student input from the previous questions in such an exposition, this will to some degree make students involved, I expect.

⁴ Having sufficient student interaction (a rough measure would be that students talk more than the teacher) is one basic requirement of a more constructivist design. Making that input matter by using it in a recognisable and meaningful way is another.

thinking? An overview of relevant research in understanding of causality in children and adults, both from the field of research in developmental psychology and the field of science education research is given by Grotzer (2003).

In Grotzer's meta-study she distinguishes four dimensions of causal complexity in models, namely mechanism, interaction pattern, probability and agency. For instance agency, where we locate the source or locus of a cause, ranges from a central and direct agent to highly emergent causality, with various levels in between. The research she discusses is organised around this taxonomy, so that most of the mentioned studies address the development along one dimension from this taxonomy, or focus on one level within one dimension.

The main body of the paper goes into what research has to say about each of the elements of her taxonomy. One section is headed, for example, 'what does the research tell us about children's ability to consider that agents do not always have direct and immediate influence over effects'. Other sections address the other elements of her taxonomy.

If it were the case that the explanatory scheme involves mainly the more complex forms along each dimension of the taxonomy, this kind of research would suggest that trying to use the explanatory scheme as I have been using it is very ambitious. The explanatory scheme itself does not easily fit into the taxonomy, but it does contain rather difficult elements that need to be explicated in relation to each other. These elements, like distinguishing between influences, causal factors and regularities, can (arguably) be placed high in Grotzer's taxonomy for the dimensions 'mechanism' and 'interaction pattern'.

All the research Grotzer mentions seems to be mainly concerned with breaking down causal thinking in various elements (like the ones used in the taxonomy), describing the (development of) understanding of children of one or more of these causal elements and identifying problematic areas in this understanding. It is mainly descriptive. In contrast, in my research I tried to *use* causal thinking instrumentally in teaching/learning mechanics. The explanatory scheme not only describes causal thinking, but was meant to become a tool for students. Since it mainly concerned description, the research Grotzer mentioned gave no clues as to how elements of causal thinking could become tools in teaching/learning some scientific topic. She suggests that "broadening students' causal repertoire within the context of a given science concept will increase the likelihood that they will develop deep understanding of the concept", but how this should be done for a particular science concept remains unanswered.

Grotzer's work did lead to appreciating the importance of making the explanatory scheme as simple as possible, by succinctly expressing its bare essence. The explanatory scheme can for instance be expressed as 'whenever there is a deviation from how something would move of itself, you search for some cause for that'. This basic causal notion does not seem that difficult in terms of Grotzer's taxonomy. This may help in facilitating the scheme's explication.

4.2. Making the design more bottom-up

The second main problem in the design was how to make the design more bottom-up. Also for addressing this difficulty practically no guidance can be found in the literature. Let us take for example the advice given by Leach and Scott for designing science teaching sequences (Leach & Scott, 2002). This is one of the few articles that actually tries to give some general guidelines for designing teaching sequences.

Their generalised approach to inform the design of teaching sequences is:

1. identify the school science knowledge to be taught;
2. consider how this area of science is conceptualised in the everyday social language of students;
3. identify the learning demand by appraising the nature of any differences between 1 and 2;
4. develop a teaching sequence, as redefined earlier, to address each aspect of the learning demand.

Further advice is given in how a teaching sequence can be conceptualised from a social constructivist perspective. Leach and Scott distinguish three features: staging the scientific theory, supporting student internalisation and handing-over responsibility to the students. These are not successive phases, but overlap each other.

In staging the scientific story the topic is made available in an interactive ‘performance’ guided by the teacher and involving various activities. The unfolding of the scientific point of view needs to take students’ existing understanding into account and be convincing so that the scientific story appears intelligible and plausible to the students. This staging also needs to find a balance between presenting information (focussing on the authoritative function) and allowing opportunities for exploration of ideas (focussing on the dialogic function). In supporting student internalisation, Leach and Scott emphasise the continuous monitoring of, and responding to, students’ understanding, for which student input is required and needs to be harvested through for instance whole class questioning and discussion. In handing-over responsibility to the students, they start applying the new ideas, where the support and assistance of the teacher is gradually diminished. This way of conceptualising teaching sequences emphasises “the way in which the teacher works with students to ‘talk into existence’ (Ogborn *et al.*, 1996) the scientific story” (Leach & Scott, 2002, p. 124).

The need to find a proper balance between presenting information and allowing opportunities for exploration of ideas seems to say something about the problem of making the design more bottom-up. At least Leach and Scott identify a similar problem, but apart from expressing that one needs to find such a balance, they do not indicate how this can be done. Furthermore, this distinction in only these two functions seems somewhat thin. Making the design more bottom-up would involve more than only choosing between presenting information or allowing exploration of ideas.

The general advice Leach and Scott give does not help either. Without much trouble I can fit my design in this perspective. I adhere to a similar view on teaching/learning as Leach and Scott and have followed (unintentionally) the given advice for designing a teaching/learning sequence. My identification of the learning demand in particular is

extensively spelled out in my problem analysis of the learning difficulties in mechanics (see chapter 2 and 3). Also much attention was paid to the way in which the teacher works with students, which was made explicit in my scenario (chapter 5). This general advice does not provide much guidance when it comes down to the actual nitty-gritty of designing activities in some teaching/learning sequence.

5. Possible solutions and further research

In this section I will present two ideas that may prove useful for addressing the two main problems in the design as well as the problems in the execution of the design. The first idea is to educationalise a practice. The second idea is to devise proper interaction structures. I will present both ideas subsequently and discuss how I think that they might help in solving the encountered problems. Finally, in section 5.3, I will speculate whether perhaps the idea of using an explanatory scheme may be applied to, and useful for, other topics or subjects.

5.1. Educationalising practices

The idea of educationalising practices surfaced in the Centre for Science and Mathematics Education in Utrecht (Bulte et al., 2002), (Bulte, Westbroek, Rens, & Pilot, 2004). I will give a very brief outline of this idea here, assuming the reader is familiar with activity theory. A more extensive presentation of this idea can be found in the mentioned papers by Bulte et al. The basic idea of educationalising a practice, where the term ‘practice’ is used similarly as it is in (neo)Vygotskian activity theory, is that a professional practice that is by its nature purposeful for those who participate in it may be adapted for use in school in such a way that students can also recognise and appreciate its purpose. Within such an adapted or ‘educationalised’ practice students could then learn the things we would like them to learn in a meaningful way⁵. The adaptation would consist of making a coherent and recognisable part of the practice fit the boundaries set by a school environment, so that goal and characteristic procedure remain or become sufficiently clear to students⁶. An important aspect of educationalising a practice is letting students and teacher adopt recognisable roles that are derived from the practice and that are used consistently.

Relation with problem posing

The relation with a problem posing approach lies in the fact that sometimes a characteristic procedure can be identified within a professional practice that, when properly adapted to an educational setting, could guide the teaching/learning process by suggesting directions in which to continue. This guidance can occur because steps in the

⁵ For a discussion of the concept ‘meaningful’ I refer to Westbroek (2005), who identifies three characteristics, namely *context* (or *practice* in the sense used here), *need to know* and *making student input matter*.

⁶ A ‘sufficiently clear’ characteristic procedure can still be pretty vague, as long as it can function in suggesting to students directions for a next step in the teaching/learning process. The procedure itself can become more clear along the way, which can be an educational goal in itself.

direction suggested by the procedure can be made to correspond to the extension of knowledge that the course(designer) intends. The procedure furthermore guides the reflection on what is done by raising the question about the status of completion of the procedure. Students can therefore know by means of the characteristic procedure at all times where they are and where they are going. They also have to want to go where they are going. Therefore, the goal to what the characteristic procedure or the practice as a whole leads must be appreciated. The choice for a practice (to be educationalised) should take into account whether students can recognise and appreciate the nature and relevance of the goal this practice is aiming at. A suitable practice makes it clear for students what it is, it is trying to accomplish, which should be something considered worthwhile. The procedure within such a practice should characterise the practice (therefore 'characteristic procedure') in the sense of fulfilling an important function within the practice, but has not necessarily to completely cover the whole practice. For instance the characteristic procedure for testing water quality (Westbroek, 2005) characterises the professional practice of testing and judging water quality, but the latter involves *all* aspects of this professional practice including the report of findings, acquisition of new assignments, et cetera.

Could this idea apply to my work?

Since mechanics is a rather theoretical topic, educationalising a professional practice is more difficult than it would be for practical topics. A practice from which a characteristic procedure may be obtained could be the academic practice of 'constructing theoretical knowledge'. Within this practice people are researching, investigating, explaining, understanding and predicting phenomena. A well known distinction in this practice is to separate the context of discovery from the context of justification⁷. I will organise my discussion of how the idea of educationalising practices could apply to my work around the two mentioned contexts.

There are no procedures for discovery in the sense of mechanical, repetitive, step by step guidelines for discovering things. If there were, we could all learn them and start discovering things. However, we can take the underlying idea of a characteristic procedure to be to divide the process in for students understandable steps, that will lead in a for students recognisable way to the particular goal the characteristic procedure aims for. In the case of the work of Westbroek, this division lead to a characteristic procedure for judging water quality, which was a quite practical, mechanical, procedural course of action. In my case I could apply the underlying idea to the academic practice of constructing theoretical knowledge by dividing the main question of 'how does explanation of motion work?' into the sub questions 'how does something move by itself?' and 'what influences are working in this situation?' This division can be expected to guide the teaching/learning process in a for students recognisable way, since it uses the basic notion that 'an influence causes a deviation of the way something would move by itself'.

⁷ This distinction has been attributed to Reichenbach and Popper and was later much criticised, for instance by Kuhn (1962). The philosophical ins and outs of this distinction need not concern us here.

In the context of justification some guidelines can be identified like epistemic virtues. This central role of epistemic virtues was also identified by Leach and Scott as an important element of the scientific practice:

Thus the *scientific* social language, the scientific way of talking and thinking, is that which has been developed within the scientific community. It is based on the use of specific concepts such as energy, mass and entropy, it involves the development of models which provide a simplified account of phenomena in the natural world, and it is characterized by certain key epistemological features such as the development of theories which can be generally applied to different phenomena and situations. However, it is not the case that ‘anything goes’ in the generation of scientific knowledge, as this knowledge should, in principle, be consistent with empirical evidence about the material world. Scientists are not in a position to create their social language in isolation from empirical data. (Leach & Scott, 2003)

The epistemic virtue of general applicability is explicitly mentioned. The last remark about consistency with empirical evidence can be read as indicating the epistemic virtue of empirical adequacy. So criteria or epistemic virtues like broad applicability, empirical adequacy and plausibility play an important role in the academic practices. They also exist rudimentary in students, but need to be made more explicit in order to function in guiding the teaching/learning process, as was seen in chapter 6 section 6.

Perhaps a characteristic procedure for my design could be found in the use of criteria for valuing explanations. Explicitly using such a procedure almost guarantees that the criteria themselves become more explicit. A rough outline of the educationalised academic practice of constructing theoretical knowledge would then consist of (1) dividing the main question ‘how does explaining motions work’ into sub questions, (2) answering these sub questions, and (3) evaluating the answers using the epistemic virtues, where (1) and (2) comprise the context of discovery and (3) the context of justification. In this way it could become clear to students that they need to justify some choice between alternative theories. They will find themselves in a ‘context of justification’, with a felt need for some tool to help them choose (and value the outcome of such a choice).

Another aspect of the academic practice that may become useful in educationalising it is the academic drive of curiosity. Although students cannot be expected to have a clear notion about what academics do, they *can* be expected to know and appreciate what drives academics, namely curiosity, the desire to deeply understand how things work. This will not guide the teaching/learning process in a particular direction, but may serve in bringing the practice more alive.

How can this idea help me?

Trying to adopt this idea is useful, for it may suggest ways of addressing the identified problems in explicating the explanatory scheme and implementing the didactical structure in the activities.

Development of the use of the practice of constructing theoretical knowledge could improve the theoretical orientation (see e.g. chapter 2, section 3.1), which could help in

explicating the explanatory scheme, for it would further clarify its purpose. The question how this can be done effectively is still not answered satisfactorily. In my design the theoretical orientation was tried to be developed by means of focussing and enlarging aspects of the common practice of explaining, that all people do all the time, to use it for a particular goal, namely explaining motion in such an exact way that important motions (of for instance an asteroid moving towards earth) can be predicted with precision. In chapter 6 was seen that this can be said to have happened to some extent, but there is certainly room for improvement. Further research may shed some light on this.

Filling in consistent and recognisable roles for students and teacher would affect the kind of interaction between them (which would then have to be in accordance with their respective roles). The role perspective could help to guide the interaction, making it clearer for the teacher what kind of interaction is required. See also the next section on interaction structures. Adopting this 'role perspective' while further implementing the didactical structure in the activities may give ideas for more bottom-up activities. In addition it may help in avoiding the pitfall of too much top-down activities. The use of this role-perspective is rather speculative. I do not know yet which roles may be appropriate.

5.2. Using interaction structures

The second idea that may contribute in solving the problems in the design and the execution of the design is designing appropriate interaction structures. This is of course no new idea. I already tried to make use of interaction structures in the second trial. In this section I will revisit this idea and reflect a little on how it might be improved.

The idea of using interaction structures in the preparation of the teacher was described in chapter 4 section 3.3. Its main use there lay in addressing problems encountered in the first trial, namely the importance of proper introductions and evaluations, the attention to student input, getting the ideas and purposes of the scenario across, and instilling a sense of ownership. In chapter 6 section 3 it was seen that this idea did not function as intended, which was attributed to the fact that the second teacher was not made appreciative of the problems from the first trial. These were not his problems. So he did not perceive implementing a possible solution in the form of using interaction structures as important enough to merit a lot of time and effort.

5.2.1. Interaction structures to make the design more bottom-up

Using interaction structures could not only be helpful in preparing the teacher, but also in making the design more bottom-up. The kind of interaction and the design being bottom-up or top-down are strongly related, since a bottom-up design should start from common ground and continually use student input. Such a design should therefore allow for sufficient student input to surface sufficiently clearly, which places demands on the kind of interaction that should take place.

The kind of interaction structures that were used in the design emphasised mainly the evaluation phase, which was strongly teacher oriented (see this chapter section 3). In the

two interaction structures that were used the most, 'taking stock' and especially 'concluding', the main conclusion was meant to be explicated by the teacher in the evaluation phase. Although this explication should use as much as possible earlier student input, the description of these two interaction structures focussed on the teacher side of the interaction. This did therefore not contribute to the design being bottom-up. An improved description of interaction structures (paying more attention to the student side of the interaction) or even entirely different interaction structures may become helpful in this respect.

Of course student input as such does not guarantee the teaching/learning process to become more problem posing. On the other hand without making student input matter, it is hard to imagine students experiencing any real felt motives for a process which is apparently indifferent to their input, nor is it possible for a teacher to explicate motives which students can recognise as their own. Student input is important as feedback to the teacher on how their learning progresses. When students realise that this kind of feedback is actually used by the teacher to adjust her teaching, this will further stimulate their involvement⁸.

Again, even *recognisably using* student input is not enough to guarantee the teaching/learning process to become more problem posing. It should be used in such a way that the designed main thread of successive episodes linked by successive motives is recognised by the students as describing the process of what actually goes on in their head when they engage in the topic. For this, introductions and evaluations are meant to establish a link between the activities students are about to engage in (on one level) and the encompassing motive for the episode (on another level). Here the content perspective and the interaction perspective meet. From the interaction perspective 'making student input matter' and 'emphasising proper introductions and evaluations' can be said to be necessary but not sufficient conditions for making a sequence problem posing. The content perspective is needed to inform what a 'proper' introduction and evaluation would be, i.e. what would make the episode problem posing.

5.2.2. Interaction structures to improve the teacher preparation

The introductory course required particularly much of the teacher. The teacher needed to harvest sufficient student input on the difficult topics of explaining in general and explaining motion in particular and extract from that input the explanatory schemes, without adding too much or too little. This careful balancing between own input and making student input matter is very difficult. This difficulty in executing the course lies in the design itself and in preparing the teacher for this design. Interaction structures may be useful in addressing both aspects.

⁸ I am aware that the kind of interaction in a class, here described isolated and connected to a single episode (short term) has implications for the class culture (long term), which in turn helps or hinders the kind of interaction that can take place. See for an interesting discussion of interaction and class culture the work of Genseberger (Genseberger, 1997), which draws heavily on Habermas' notion of communicative action.

The first aspect was already mentioned in section 5.2.1. If the course were designed more from an interaction perspective, using improved interaction structures that pay attention to both teacher and student side of the interaction, this would help the teacher preparation. Also adopting roles from an 'educationalised' professional practice (see section 5.1) can clarify what is expected from a teacher in order to make the design work. I will first elaborate on improving interaction structures and then address the second aspect, how interaction structures can become useful for preparing the teacher.

Improving interaction structures

The used interaction structures emphasise the various subsequent aspects of the teacher side of the interaction. Although this implicitly suggests the student side, for instance a 'clarification' by the teacher suggests an unclear student response, making these explicit would better capture the interaction and remove the suggestion that it is mainly the teacher who is doing the talking. Furthermore, placing more emphasis on the student side may result in useful thinking about what input and reactions are actually expected from students.

For a teacher who already has a problem posing mindset the process of filling in an interaction structure for some episode naturally raises the right kind of questions (see chapter 4 section 3.3). What answers do I expect from students? How am I going to respond to these answers? Why respond in that way? How does this serve the educational goal for this activity? How can I evaluate the activity in such a way that does justice to what the students have said? Does this evaluation properly prepare for the next episode? et cetera. For such a teacher these interaction structures can be very helpful. For a teacher without such a mindset the used interaction structures as such do not necessarily start such a person in a problem posing direction. Even improved interaction structures would not change the mindset of such a teacher. For this, in addition to improved interaction structures themselves, a different way of using such structures would be required.

Using interaction structures for preparing the teacher

The potential value of interaction structures lies in their ability to enable the right kind of discussion between teacher and developer. What the developer considers important in the interaction in some episode can be made concrete by the way an appropriate interaction structure is selected and filled in. Perhaps a first episode can be filled in as an example by the researcher, thereby verbalising all considerations involved. This orientates the teacher towards those aspects of the interaction that are considered to be important (by the designer). She can then try filling in one or more herself, which can be discussed in a way that emphasises the important aspects of the interaction. From the teacher's point of view I expect interaction structures to be quite easily understandable, for they resemble well known teaching formats. Filling in interaction structures would for teachers boil down to a quite normal way of lesson planning. It would be a rather more elaborate lesson planning that emphasises different aspects, but similar enough to what they are used to. Starting from this normal use of teaching formats teacher and designer can, by discussing the filled in interaction structures, get closer and closer in a mutual appraisal of the desired kind of interaction.

Such a discussion may be further facilitated by slightly generalising the recurrent pattern of introduction, main question and answer phase, and evaluation in light of the context. This pattern was first described in the context of interaction structures (chapter 4), but can be seen to recur on several levels. It can be seen in the introductory and regular course as a whole, where the introductory course functions as setting the context for the regular course, in which then one or more main questions are answered. The regular course should then end in an evaluation in light of the context set by the introductory course. Within this overall structure of introductory and regular course smaller repetitions of the same pattern can be found, which are ‘nested’ within the larger structure. Within more complex episodes one can sometimes describe the context setting or evaluation of a complex episode in terms of a nested sub-episode.

Apart from making thinking about and discussing interaction structures easier by describing them as recurrences of the same pattern, a further use of stretching this perspective beyond the original episode application is that it forces one to think about exactly what the ‘main question’ of a topic is and how this should be introduced and evaluated (in light of this introduction). These questions can be asked and answered on every level and in this case I am inclined to say that ‘can implies ought’.

The problem remains how a teacher can be made sensitive to the kind of problems interaction structures aim to help to solve. The second teacher can perhaps be made sensitive for the difficulties in the execution of the second trial by the experiences with the first teacher from the first trial⁹. Somehow material from the first trial may be used to show the difficulties in properly introducing and evaluating the main questions in the subsequent episodes, and the detrimental effects when these fall short, in a for the teacher recognisable way. How this can be done is an open question that needs to be addressed in further research.

5.3. Other explanatory schemes?

The basic strategy that was followed and resulted in the idea to investigate the possible use of the explanatory scheme for motion in teaching/learning mechanics was that on a underlying structural level there are similarities between common sense and scientific reasoning. The specific similarity in the case of motion was expressed as the explanatory scheme for motion, and this was seen to be a special case of a basic structure in causal explaining in general, expressed in the general explanatory scheme.

One could explore this idea further and look for more similarities on a basic level in common sense and scientific reasoning. Klaassen (2003) suggests that such similarities may lead to identifying constituting elements of understanding the world. (The following citations are from the mentioned paper.) These elements “express constraints on the application of such basic concepts as those of cause, state, kind, substance and object” and could therefore be relevant in teaching/learning topics in which such concepts are used, that is almost all topics. In chapter 3 it was seen how the general explanatory scheme constrains ‘state’, ‘change’ and ‘cause’. Another example of a constituting element constraining the concept of ‘substance’ would be the basic scheme

⁹ Of course it would be preferable if the same teacher could participate in all trials.

with which both common sense and scientists (chemists in this case) classify substances: Part of what makes something a substance of a certain kind is that it behaves in a certain way in certain circumstances. What kinds of behaviour and what circumstances are considered relevant depends on one's explanatory aims and interests.

Identifying and making explicit such constitutive elements is difficult, although they may seem obvious once they are formulated. "It takes the greatest minds to articulate the constitutive elements clearly and sharply". Finding such elements is therefore a job for the great philosophers. "It is up to [... the] educationalists to explore whether and how they can be made educationally productive."

This research project was a first attempt at exploring the educational use of one example of a constitutive element. Within this wider perspective it would be premature to abandon this strategy because of the relative lack of success. It is not yet decided whether this strategy can be made to work for the topic of mechanics. That question is still open, I think. Whether the strategy as a whole will prove useful is a very wide question that will not be decided by applying it to one or two examples.