Development of a modelling learning path
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Summary

In this dissertation, I report on a design research project in which a learning path has been developed on modelling, integrated into the Dutch physics curriculum and starting from the initial phases of physics education, at age 13-14 years. With modelling, a complete process is addressed, based on the description of the general modelling competency as formulated by the commissions for renewal of the Dutch science curricula: “The student must be able to analyse a situation in a realistic context and reduce it to a manageable problem, translate this into a model, generate outcomes, interpret these outcomes, and test and evaluate the model.” In the learning path, emphasis is on modelling with computers. System dynamics based graphical modelling has been chosen as modelling approach. In the learning path, modelling is systematically combined with experimenting and doing measurements. The experiments familiarize students with the realistic situations that are modelled, the measurements provide the data that are used for evaluation and validation of the models. In this dissertation, the design of the learning path and results from field testing after several design and research cycles for the first two years of this learning path are presented.

Modelling is considered promising for education, but it still is a question how modelling can be used in secondary physics education in an effective way, for students to learn about models and modelling, and to learn physics by means of modelling. Main research questions are what can be an effective design for a modelling learning path, and what can be achieved with lower secondary students.

RQ1: What are characteristics of an effective learning path on graphical modelling in lower secondary education?

RQ2: To what extent do students learn to model when they follow this learning path?

In traditional physics education, students only study situations that are within the limits of their mathematical capabilities. Many of these situations are not realistic but simplified. Students may not be aware of the assumptions that have been made, and may be not aware that they are actually studying models. As a consequence, they fail to make links between reality and the physics learned at school. Computer modelling enables students to study subjects that are more realistic and a modelling approach can make them more aware of assumptions and the value of physics. These more realistic subjects can be
expected to be more complex. The question is to what extent lower secondary students can understand the physics of such more complex subjects. Another question is how the physics and mathematics content of the curriculum is affected by the modelling learning path.

RQ3: To what extent can students understand the physics of the more realistic and more dynamical phenomena in the modelling learning path?

RQ4: How is the mathematics and physics content of the lower secondary physics curriculum affected by the modelling learning path?

The guidelines that are used for the design of the learning path can be considered as the kernel of the answer to the first research question; they are described in Chapter 5 and result from earlier exploratory studies. These earlier studies are presented in Chapters 2, 3, and 4. The remaining research questions are answered in Chapter 8, based on findings described in previous chapters.

Regarding the guidelines for the design of the learning path, a first one is the formation of bases of orientation for new concepts. With respect to the other guidelines, a distinction is made between two educational scales: (1) a smaller scale, of a ‘modelling learning sequence’, i.e., an individual modelling activity together with the sequence of supporting learning activities around it (including the experiments), and (2) a larger scale, for describing the order in the learning path of all different activities and abilities required for modelling. Some guidelines for the design of modelling learning sequences are derived from the modelling process, but many of them originate from the educational similarity between modelling and practical work that has been established during this research project. On the larger scale, the learning path is considered as consisting of five intertwined partial learning paths. These five are partial paths on (1) the use of the modelling software, (2) graph comprehension, (3) variables and formulas, (4) graphical models, and (5) evaluation and the nature of models and modelling. The design of the learning path in terms of these five partial paths is presented in detail in Chapter 5.

The second research question is discussed from several perspectives in Chapter 8. Within the limited time span of this research project, most attention is given to the perspectives of the partial learning paths on variables and formulas and the path on graphical models. The partial path on variables and formulas is described in detail in Chapter 6. Blockages as result of too limited students’ notions of variable and formula, that have been detected in a pilot study (see Chapter 4), have been overcome by offering students operational definitions of variable and formula, by letting students use formulas in a computer learning environment, and by letting students construct simple formulas themselves. The progress in the students’ abilities to construct simple formulas is promising when compared to results of modelling in upper second-
ary education. The partial path on graphical models is presented in detail in Chapter 7. Students have successfully worked with several graphical models and have successfully constructed simple graphical models based on known equations, but only part of the students have correctly understood all aspects of the graphical diagrams. Research results show that reality-based interpretation of the diagrams can conceal an incorrect understanding of diagram structures. This incorrect understanding only comes to the fore when students are asked to construct graphical models without assistance. The model equations are not communicated clearly enough by the graphical diagrams.

Regarding the third research question, in general, students have few problems accepting realistic phenomena. Reached levels of understanding differ among students, but students applying for physics in upper secondary education have performed reasonably well on test questions about more complicated phenomena. In case students have developed only a partial understanding of such phenomena, this does not impede further learning because subsequent steps in the learning path do not depend on a complete understanding of these phenomena.

With respect to the fourth research question, four ways are distinguished in which the content of the curriculum has been affected, namely by:
1. the introduction of modelling learning sequences;
2. the introduction of more complicated subjects from physics;
3. a change of the mathematical content, necessary for modelling; and
4. a shift in the view on physics.

At first sight, modelling is expected to decrease the mathematical load for students, but it turns out that modelling puts higher demands to the students’ conceptual mathematical understanding than usual in lower secondary education. Some physics subjects have been studied more intensively and on a higher level than usual as a result of the integration of modelling, but at the expense of attention for other subjects. Finally, modelling takes time, but this time may be well spent, because of the value of modelling as a general competency, that is useful for other disciplines as well.

This research project has shown that it is possible to start with modelling in lower secondary education, provided that sufficient attention is paid to modelling-related student difficulties. The learning path is to be extended into upper secondary education in future.