7. General conclusion & discussion

This final chapter brings together for a comprehensive reflection the findings and conclusions of all the separate studies. In the first section below the research questions are repeated. In the next section those questions are addressed by providing a chronological summary of the findings of each study. We will end with some remarks on educational theory and practice and propose some suggestions for further research.

The overall research question of this design-based project was the following: do students, who participate as model designers in a process of guided co-construction with an expert (teacher) and peers, show better learning outcomes than students who learn to work with ready-made models provided by the teacher? The general, working hypothesis is that collaboratively learning to design and use models in vocational education has positive effects on learning outcomes, compared to providing ready-made models to the students. The basic idea underlying the hypothesis is that students will develop knowledge and skills in modelling along with codified knowledge in mathematics and science as a result of constructive involvement and dialogic inquiry under teacher guidance. In all three interventions the students were to design and construct a technical product in the form of a tandem tricycle (in the first case study a bicycle racing game was the second product). The overall research project was divided into three interventions: a case study, and two experiments in a pre-test post-test control group design. These interventions resulted in four studies (see below).

Summary of the results: a narrative of the design-based research

Case study (Study 1)

The first questions we addressed in Study 1 were: (1) What teaching/learning processes occur in a simulated workplace using the concept of a knowledge-rich workplace? (2) What is the role of models and modelling in the teaching/learning processes?

In a case study (chapter 3; Van Schaik, Van Oers, & Terwel, 2010a) we explored the implementation of two assignments and the subsequent teacher guidance at one school and tested whether or not the learning environments became knowledge-rich (Guile & Young, 2003) as a result. Knowledge-rich workplaces are assumed to engage students in meaningful activities and at the same time promote subject matter learning (including mathematics, see Kent, Noss, Guile, Hoyles, & Bakker, 2007). In other words, the learning environment has the potential for students to acquire knowledge that is codified or disciplinary. The results showed that designing a tandem tricycle did, in fact, create opportunities for teaching students codified knowledge and modelling. The teachers, however, tended to simply provide ready-made models while for the students the knowledge involved remained situated. That is, as solutions to problems, mathematical and scientific concepts and models tended to be bound to the (practical) situation in which they were constructed. Although the assignment itself was potentially knowledge-rich from the teachers' perspective, students could not relate the provided problem solving models to more general codified knowledge. Our assumption is that if the models had been designed by the students under teacher guidance, the role of models as tools would have become clear and the relation between theory and practice might have become more transparent in the process.

We also learned from the case study that student design processes should not be disconnected from actual construction; not only for motivational reasons (students who did not construct their designs were disappointed), but also because the transitions from design to construction turned out to be the most interesting. Moreover, the verisimilitude of the situation was also important for student motivation: "Clients should not be teachers playing the client", as the students put it. Interestingly in this connection, the students that had a primary school as client proved more motivated than the others.

First experiment (Study 2)

Next, for Study 2, two conditions were shaped in a pre-and post-test control group design: a 'providing' condition (control group) and a 'guided co-constructing' condition (experimental). The research question addressed the differences between the conditions and was divided into three subquestions:

1. Do students in the experimental condition acquire more knowledge and a better understanding of mathematics and science?;
2. Do students in the experimental condition develop a better understanding of the use of models?; and
3. Do students in the experimental condition produce better models/drawings of their own products?

The first experiment was an intervention at two schools following the case study. A programme based on the tricycle assignment was designed and teachers were trained to guide the students either in a co-constructive or in a providing way (chapter 4; Van Schaik et al., 2010b). In the subsequent experiment the two conditions, providing (control group) versus guided co-construction (experimental), differed in the way models were used in the classroom. In the control condition models were drawn by the teacher and functioned only as a fixed representation of the product, as opposed to a developing tool for orientation and communication. In the guided-co-construction condition models evolved into thinking tools for students to help them orientate towards the situation, and communicate with each other and the teacher on their plans and ideas. The results of this intervention showed that there was no difference between the conditions with respect to scores on the posttests on codified disciplinary knowledge. However, the students in the experimental condition produced better models of their products.

In this experiment we also learned that the drawings and models seemed to disappear during the process. For the purpose of examination we created some prototype lessons for the next experiment in order to create moments for explicit attention to designing a tandem tricycle and connecting practical problems to codified knowledge. In addition, we also observed that practical issues, such as the availability of materials for students, were often decisive for the final form of the tricycles. However, the students did not often adjust their construction drawings and so the design failed to be consistent with the final product. As a result, the assignment in this experiment contained an additional requirement to the effect that in the end a drawing of the product as it actually was constructed was added. Given the key finding that the workplace presence of models proved crucial, the next study focused on video observations of (verbal) interactions on models.

Final experiment (Study 3 and 4)

In Study 3 (chapter 5; Van Schaik, Terwel & Van Oers, submitted a) addressed the question: by designing a real product themselves guided in a co-constructive way, do students gain codified knowledge and a better understanding of modelling? In this second experiment students in the experimental condition did not outperform their counterparts in the control condition on knowledge and modelling. Although the school that produced relatively high scores was in the control condition, differences on the post-test were not explained by condition. Besides the pre-test, school was the variable that correlated with the scores on the post-test. However, a comparison between the schools did not result in a significant difference between the schools. Consequently, our hypothesis had to be rejected.

In Study 4 we continued our analyses by an in-depth qualitative study to find the determinants that might explain differences in learning outcome at school level. First of all, in Study 4, the goal was to examine precisely how the design was enacted at each school. Next, we aimed to establish how the activity of modelling developed with the process of constructing a tandem tricycle. Moreover, we sought to find out if modelling actually brought together practical experiences and the codified theories of the general curriculum. Hence, the two questions that arose in this last study were the following: (1) What was the actual teaching/learning practice at the schools and how did the schools differ, especially in the way the models functioned as tools in the design process of the students? (2) Was the teaching/learning practice aimed at designing and understanding related to disciplines, both academic and vocational? We conducted qualitative micro analyses in order to find out how models functioned in classroom practice and how teachers guided the design process. The conclusion was that the use of models at two schools resembled the practice of professional designers more than at the other schools (MacDonald & Gustafson, 2004). Teachers and students used their models as tools for orientation and communication, which engaged the students more authentically in the reality of the workplace. As a result, the formation of their disciplined perception (Stevens & Hall, 1998) was presumably better supported at these schools (chapter 6; Van Schaik, Van Oers & Terwel, submitted b).

All in all, the question whether or not students show better learning outcomes when they are the model designers in knowledge-rich simulated workplaces in a process of guided-co-construction remains unresolved. Based on the tests in the two experiments, the conclusion is that there is hardly or no difference in learning outcomes compared to students who had ready-made models provided. However, two findings lead us to believe that guided-co-construction might improve the students' understanding of modelling and codified knowledge. First, the students in the experimental condition in the first experiment produced better models. This may have been due to the fact that the teachers used their models as communication and orientation tools (chapter 4). Secondly, at two schools in the final experiment more interactions on models were found, while models were part of the process for a longer time (chapter 5). Moreover, the models were in a more finalised state. We therefore concluded that the students' design process at those schools resembled that of professional designers more than that of the students at the other schools. Our impression was that disciplined perception is better supported at schools where designing is integrated into the activities of the simulated workplaces. As a consequence students' understanding and knowledge are enhanced (see chapter 6). This leads to our overall conclusion that the use of models as tools for communication and orientation in product-oriented vocational practice resembling that of professional designers, help students develop better understanding, while codified knowledge of both academic and vocational disciplines is enhanced.

In addition to addressing the overall research question the four studies also resulted in a closer analysis of the research process and, in particular, the use of video in design-based research (chapter 2). In retrospect we can see that the extensive use of video data co-determined the course of the research trajectory in ways that would not have been possible with quantitative data alone. On the basis of the quantitative data we would have concluded that the research conditions in the project (providing versus co-constructing models) did not work out as predicted in our context of knowledge-rich environments. On the basis of our workplace observations we were able to refine the guiding principles of the design and conduct a replication study which resulted in basically the same outcome as the answers to our main research questions. Through the use of video data from workplace activities of students and teachers the redesigned project enabled us to determine that the use of the models differed at the different schools. We were even able to speculate about conditions that might be conducive to such situations. As a result, our attempts to find an answer to questions on the learning of codified knowledge in simulated, knowledge-rich vocational education obviously needed a new theoretical refinement that no longer focused on examining the possible value of broadly defined conditions such as 'guided co-construction', but concentrated on actual microgenetic learning trajectories in the use of modelling (as a tool for orientation and communication). A decade of studies on the issue of providing versus co-construction has reached a new stage with the help of detailed video-analysis, which can be defined as a study of providing in the context of guided co-construction and ways of supporting the meaningful use of tools and codified knowledge in students' problem solving during the processes of construction and design.

Discussion

Among the first few empirical studies of Dutch pre-vocational education (e.g. Boersma, Ten Dam, Volman & Wardekker, 2009; Koopman, Teune & Beijaard, in press; Van de Pol, Volman & Beishuizen, in press) this study is the only one that combines the perspective of the students and the role of the teachers by using an intervention that incorporates process data (e.g. video) and output measures (knowledge tests). It resulted in findings that are in line with the other studies. With Boersma et al. (2009) we agree that students are motivated by 'real' assignments. That is, tasks which, as Koopman et al. (in press) argued, should be oriented towards delivering a 'product'. The fact that we observed only two schools at which teachers were able to link students' practical problems to theory, concurs with the results in Van de Pol et al. (in press), in which observed teachers showed few examples of guidance that were contingent on student capabilities.

Given that we only found minor statistical differences, further study of the complex environment will have to be considered. Strict control of the conditions proved impossible, while a fidelity approach would have been counterproductive in this rather loosely organised school sector. As a consequence the design implementation differed considerably among schools (see chapter 5 and 6). Since student groups and teacher teams are especially unstable in pre-vocational education, a larger sample could only partly solve that problem. We also know from our logs, observations and interviews that adaptation to the local school context does not ensure implementation of the intervention as intended. The concept of mutual appropriation may therefore be the correct one to gain insights into the dynamics of interventions in (pre- vocational) education, with the researcher(s) on one side and teacher(s) on the other (Downing-Wilson, Lecusay & Cole, in press).

Taking the conclusions of the four studies in this dissertation together with the analyses in chapter 2 of the development of the intervention, we propose three suggestions for the modelling curriculum in (pre)vocational education. The first suggestion addresses the content of teaching; the second suggestion, on how the teaching-learning processes could be shaped, is more pedagogical in nature; the third suggestion describes the assignments.

With regard to the content of modelling teaching in vocational education, the focus of teacher guidance should be on the process of designing. Since we learned that those schools performed best at which the enacted curriculum project resembled the practice of professional designers, the suggestion is that when students act as designers they learn better how to use models and reach acceptable levels of knowledge. Moreover, models that are used as tools for orientation and communication and utilised in combination with teacher guidance, can support student understanding as well as enhance the knowledge codified in academic and vocational disciplines.

It follows from the above considerations that teacher guidance is crucial. Two main characteristics can be formulated from our studies. First, teachers who are capable of explicitly integrating theory and practice through their academic background guided students to better (use of) models. Teams of teachers should therefore be composed in such a way that at least one of the teachers has an academic background and is able to connect that to the workplace. This way students can be guided towards concepts, rules and principles of academic and vocational disciplines by working on practical assignments. Secondly, as we saw, when students work on their own design and draw models themselves their own models are more elaborate, and they perform better on modelling tests. Hence, teacher guidance should have a student's' own design as its starting point.

Finally, for the assignment it proved important that it was 'real' and complex. Students were motivated to work on products that could be used as real products. Although the assignment in the two experiments had no clients, the prototype competition was real enough. In addition, to promote understanding and codified knowledge, assignments need to be complex, though not too difficult. The tricycle assignment had the right balance in this respect. It was complex enough to connect practical problems to academic as well as vocational disciplines, such as are, for example, manifested in the concepts of transmission and the principles of designing and modelling. At the same time the assignment proved not too difficult, since most students were able to finish the product.

In light of the above, the discussion about providing versus guided co-construction can be taken a step further by specifying in greater detail what teachers really do, where, when, and finally how their activities are related to learning outcomes. In other words, the proposed focus for future research consists in the further elaboration of the different forms of guidance (by instruction, discussion, etc.) in workplace contexts and how such forms could support students' development towards expertise in the vocational practice. More detailed studies are required into the development of disciplined perception and into ways in which such development could be stimulated in workplace settings.

Further research should also explore a teaching/learning strategy that incorporates actual school practice. In ideal practical situations students design and construct complex 'real' products, guided by teachers who are able to connect practical problems to disciplinary theory, while the students' own designs form the basis for guidance. Only approximations to such situations could explain what guided co-constructing means for teaching and learning in general, with specific reference to (pre)vocational education.

At this stage the empirical relevance of these practical implications to educational theory needs to be addressed. First of all, in the course of the three interventions we developed the concept of a knowledge-rich learning environment in vocational education. We started by stating that it should be an environment in which students acquire more than just practical skills. Codified knowledge should also be imparted in such an environment. Our final impression is that if the concepts of both Guile and Young (2003) and Stevens and Hall (1998) are connected, the learning environment has the potential for students to acquire codified or disciplinary knowledge. Furthermore, the results of the two experiments have led to an improved understanding of how models work as tools in vocational education and that the use of such tools may result in acceptable knowledge levels (i.e. scores above 50 per cent on posttests). Our view of models as tools for orientation and communication was enriched by the way models work in a design process in school practice (MacDonalds & Gustafson, 2004). Finally, we now have additional proof that guided co-construction as a teaching-learning strategy works in pre-vocational education. Furthermore, the nature of what constitutes relevant guidance has been further elaborated (see for example the suggestions above). While working on real products VMBO students need the type of guidance that leads them from their own designs and models to the knowledge codified in vocational and academic disciplines. Such guidance must explicitly connect theory to practical problems. Only in that way will students be able to learn to recontextualise their practical knowledge within the system of codified disciplinary knowledge. Such recontextualisation will improve their practical skills as well as their theoretical knowledge. In short, our theory of modelling in vocational education has now been connected to VMBO practice.