Co-constructing Models as Tools in Vocational Practice

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Co-constructing models as tools in vocational practice

Learning in a knowledge rich environment

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
prof.dr. L.M. Bouter,
in het openbaar te verdedigen
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De Boelelaan 1105

door

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geboren te Bodegraven

promotoren:	prof.dr. J. Terwel
	prof.dr. B. van Oers

“Sir, today I used Pythagoras' theorem three times.”
(a student, not a part of the sample, to the teacher)

A silent revolution in VMBO

Less traditional subject and brand new classrooms: preparatory senior secondary vocational education – celebrating its 10 year anniversary – has changed dramatically. “Teachers in VMBO primarily think: what do our students need?”

(Trouw 10-10-2009; Van der Waals 2009)

“Let your mind work!”
(teacher to student)

“See, you don’t even can recall it anymore.”
(Sander to Ryan)

“It doesn’t matter, we’ll see to what it leads us.”
(student to student)

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1.

General introduction

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Dutch preparatory senior secondary vocational education[1] for 12-to-16-year olds (VMBO) started in 1999 and was intended as an educational innovation (Van der Waals, 2009). Traditionally, vocational education mainly focused on training technical and vocational skills. However, in the 1980s, theory-based learning became the focus for VMBO predecessors. Neither of the two approaches was satisfactory. The first (practical) approach could not optimally stimulate the broad development of students, the second was often too difficult or resulted in meaningless mechanical learning. Presently in VMBO, teams of teachers are trying to find the right balance between theory and practice. Van der Waals (2009) calls this innovative development at VMBO a 'silent revolution'.

Within the European Union and elsewhere it is recognised that in order to prepare students for the demands of the future, they should obtain competencies that cover both broad general knowledge as well as technical skills (Cedefop, 2009; Commission of the European Communities, 2008). However, there is an ongoing debate on how to connect formal learning and learning in the workplace (Billett, 2003; Griffiths & Guile, 2004; Guile & Griffiths, 2001; Tuomi-Gröhm & Engeström, 2003). At the same time, little research has been conducted into the learning environments in vocational education that are expected to promote this kind of learning (Koopman, Teune & Beijaard, in press). For example, a query in the ERIC database with the keywords "workplace learning", "formal", "informal" returned 44 journal articles of which 14 concerned vocational education. None of them were empirical studies investigating the learning environment. Another search on on pre-vocational education journal articles at the secondary level returned 15 hits, three of which concerned the learning environment. This thesis reports a research project in Dutch pre-vocational education which investigated an intervention aimed at promoting students' codified subject matter knowledge and their understanding of modelling during the design and construction of a technical product (e.g., a tricycle or a bicycle race game).

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[1] VMBO is preparatory senior secondary education. It is Dutch secondary education for students 12-16 years that prepares them for senior secondary vocational education. About 60% of all Dutch students 12-16 years attend VMBO (Maes, 2004). We use (pre) vocational education in this dissertation to refer to VMBO.

As an attempt to improve the relevance of the knowledge and the effectiveness of transfer to the workplace, reforms are taking place in Dutch pre-vocational schools (De Bruijn, 2004; Guile & Young, 2003; Seezink & Van der Sanden, 2005), as in other countries. One of the proposed reforms envisions the teaching-learning process as an activity embedded in a simulation of real world practices, whereby students, guided by teachers, work on products for 'real' customers, in the meantime acquiring new knowledge and skills. The basic assumption behind this approach is that the learning of codified knowledge and vocational skills can be integrated into authentic workshop practices. The pedagogical approach is what Tynjälä labels "integrative pedagogics", which is more of a principle integrating theory and practice than a specific teaching method (2008, p. 144). However, working on a (practical) problem is not enough to motivate students to learn (Guile & Young, 2003), and participating in real life situations is not sufficient to develop expertise on a higher level (Tynjälä, 2008). Explicitly taught knowledge, for example knowledge about modelling or knowledge gained in mathematics education classes, is not automatically used for problem solving in a workshop setting, and vice versa. Students simply do not recognise the connection between theory and practice. This may result in reduced learning outcomes and lack of motivation on the part of students. The challenge for schools is to provide assignments that are meaningful for students and realistic with regard to their future work (Terwel, 2009; Tuomi-Gröhm & Engeström, 2003; Volman, 2006). At the same time, those assignments should also result in highly qualified learning outcomes that enable students to recontextualise their knowledge and skills acquired in the classroom to the workplace. Teaching should support students in relating practical problem solving to codified curriculum knowledge (Guile & Young, 2003; Van der Sanden, Terwel, & Vosniadou, 2000). It follows therefore that students, when solving real life problems, need to be supported by "conceptual and pedagogical tools which make it possible for them to integrate theoretical knowledge with their practical experiences." (Tynjälä, 2008, p.145).

Real workshop activities could increase the need for specific knowledge and skills, and subsequently provide opportunities for learning. Following Guile & Young (2003), such workplaces can be characterised as a "knowledge-rich workplace" (p.73). They are assumed to engage students in meaningful activities while at the same time promoting subject matter learning (including mathematics, see Kent, Noss, Guile, Hoyles, & Bakker, 2007).

Models as tools

In vocational education, students are sometimes involved in such knowledge-rich workplaces while designing and constructing real products. In the design process as well as in the actual construction issues arise that need to be solved. To anticipate possible problems and their solutions models may be used. Although drawings and models are important in the design of technology and serve both to communicate and generate ideas, MacDonald & Gustafson (2004) claim that in classrooms the emphasis is on their mere representational function. Students have to draw correctly, while their models are only used for teacher diagnostics. If in these types of environment student drawing were related to orientation in the problem situation as well as to an exploration of ideas, modelling might turn into action-cum-learning strategies by which students could gain deeper understanding of problems and their possible solutions.

Following Van Oers (1988), a model is defined in this thesis as "… any material, materialised (for example a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's action …" (p.127). These models function as tools in activities for orientation and communication, in ways similar as described by Tuomi-Gröhn and Engeström (2003). For example, a model may allow the designer to calculate angles in a drawing in advance, for example to correctly saw steel in a single process rather than by trial and error. Here the mathematical formula functions as an orientation tool. When the drawing is then used by students to negotiate the design, it becomes in addition a tool for communication. Hence, orientation and communication are both functions of a model, and a model can serve both at the same time.

From a sociocultural point of view models have two core functions: orientation and communication. These functions are not mutually exclusive. Orientation, according to Galperin, is essentially a psychological action moment. This process acquires a cultural form which is characteristic for a certain practice, leading what is usually called 'disciplined perception' (Stevens & Hall, 1998). Models play a particularly important role in this process: a model is a cultivated tool for orientation towards future actions (Van Oers, 2006), providing direction to someone's activities. Orientation includes valuation, produces information, and functions as a basis for plans and predictions. As tools for communication, models foster the distribution of individual ideas and meaning across the community. When students work together, as in our case on the construction of a tricycle, they utilise drawings and ideas to plan and predict the process, and to discuss the final design. The models provide direction not only to the actual design and the planning of the activities but also to the coordination of ideas and actions among the participants. In other words, the models assist in anticipating the outcomes and meaning distribution in a community (Gal'perin 1969;1979 in Van Oers, 2006).

Modelling in the practical workshops in vocational education can serve both students' technical codified knowledge as well as the more general type of knowledge in subjects such as mathematics and science. In contrast to simply looking at a technical artefact or making a practical construction, by collaboratively designing models during the construction process students are faced with a newly emerging dimension, by which the basic structure of the construction is uncovered. The new dimension provides insight into how elements relate to each other and how technical artefacts work, for example a tricycle (cf. Verkerk, et al. 2007). As a result, the student is not only able to see the tricycle as a working means of transport, but also to conceive of it as a concrete specimen for the transmission of forces.

Guided co-construction

Introducing students to certain sociocultural practices (e.g., workplace as well as mathematical practice) is best described as a process of legitimate peripheral participation (Lave & Wenger, 1991; Mercer, 1995). In such a context learning may be seen as a process of qualitative change in activities, resulting in enhanced possibilities of sociocultural participation (Van Oers & Wardekker, 2000). When learning takes place in a workplace setting the agents involved (students and teacher) may be characterised as a community of practice (Lave & Wenger, 2005). In these communities the participants share basic assumptions about rules and purposes. As learners they are actively involved in meaning-making activities, as well as in problem solving with the support of tools and artefacts, while communicating with each other as well as with others outside the community.

Furthermore, empirical analysis has shown that in the accomplishment of activities new goals and needs may emerge which drive participants to construct or adopt new tools (cf. Kozulin, Gindis, Agayev, & Miller, 2003; Saxe & Guberman, 1998). Hence, by participating in communities, students may be compelled to aim for new goals that encourage them to adopt appropriate new practice-related tools, including concepts, symbols and models (Gravemeijer, Lehrer, Van Oers, & Verschaffel, 2002). In guiding the participation process teachers help their students understand the use and meaning of the concepts, symbols and models as tools in a range of similar practices. At the same time the teachers themselves are participants in the same community, as much involved in the co-construction process as the students. It is important to remember that the teacher is not just a guide in this process of meaning making, but also a genuine participant (Van Oers, 2001). For example, the teacher may help students create a construction plan by asking questions while referring to both domain specific drawing rules as well as the relevant mathematical concepts. In other words teachers participate in the teams not only as guides but also as experts.

Guile and Young (2003), however, argue that for knowledge acquisition in a 'community of practice' participation alone is not sufficient. Teachers should explicitly focus on relating both situated and more general knowledge as codified in the curriculum subjects. In our intervention the curriculum project was aimed precisely at this objective: moving from practical problems to modelling, and, eventually, to an understanding of the relevant domain-specific concepts.

The important role of the teacher, as a guide to knowledge acquisition and understanding in practical environments, also includes introducing students to the practice of modelling with the aid of mathematical tools. The teacher's role is to identify what is 'mathematical' in the workplace practice, to recognise the students' emergent need for mathematical tools, and to relate such recognition to the practice of (mathematical) modelling (Van Oers, 2001). In other words: to help students become familiar with the modes of thought that prevail in the discipline (Stevens & Hall, 1998). The discipline is in this case both vocational and academic. However, simply providing models is not sufficient for understanding the use of models as tools; in addition, conditions should be created which focus "… on the hidden rules and assumptions in the tools." (Van Oers, 2001, p.81). Teacher guidance should therefore promote such understanding by helping students to co-construct the models.

One of the major issues in theories of learning to model involves the question: Are models to be provided or generated? We have theoretical reasons and empirical evidence from earlier research projects in the mathematical domain to the effect that guided co-construction – as a third way in this dilemma – is an effective teaching and learning approach compared to the simple provision of ready-made models by the teacher (Poland, 2007; Terwel, 2004; Van Dijk, 2002). However, questions for further research remain. The outcomes of a number of other studies into the design and use of models in mathematical problem solving show that self-constructed models do not always have the intended effects. (e.g. Perkins & Unger,1999; De Bock, Verschaffel, Janssens, Van Dooren, & Claes, 2003). In addition, as mentioned earlier, little is known about modelling in the vocational (technical) domain. It was against this background that the present study was planned and conducted.

Research questions

The theoretical background sketched above leads to the following overall research question: 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 for this study is that collaborative learning to design and use models in vocational education has positive effects on learning outcomes, as 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.

The overall research project was split 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). For every study the specific research question differed. The first questions we addressed in Study 1 (case study) 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 teaching/learning processes?

Next, for the first experiment in 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 the following 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 do students in the experimental condition produce better models/drawings of their own products?
3. Do students in the experimental condition produce better models/drawings of their own products?

Finally, Study 3 (a quantitative study of the second experiment) addressed the following question: by designing a real product themselves, guided in a co-constructive way, do students gain codified knowledge and a better understanding of modelling? However, since the test data did not show significant results at the level of condition (experimental treatment) we continued with Study 4 (also incorporating additional qualitative data) in order to find the determinants that might explain the differences in learning outcome at school level. The first goal of Study 4 was to find out how exactly the design was enacted at every school.

Next, we wanted to establish how the activity of modelling developed with the process of constructing a tandem tricycle, and, in addition, whether the process actually brought together practical experiences and the codified theory of the general curriculum. This led to the following two questions: (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? (2) Was the teaching/learning practice aimed at designing and understanding related to the disciplines, both academic and vocational?

Design

This study may be regarded as a design experiment (Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004; The design based research collective, 2003; Shavelson, Phillips, Towne & Feuer, 2003). For the first three studies we designed and redesigned an educational curriculum project and implemented it. Details on the development of the intervention and the way in which video, among other data, guided our research can be found in Chapter 2.

Study 1, a case study, tested an assignment. Without further specific adjustments to the school learning environment, the study was designed to determine whether or not the assignment was knowledge-rich. In Chapter 3 we describe how students designed and built a tandem tricycle and how knowledge developed.

Second, for Study 2, the first experiment, the tandem tricycle assignment was redesigned as an intervention implemented at two schools. The schools were divided into two conditions. In the experimental condition teachers guided the students in a co-constructive way, whereas in the control condition the pedagogy was more traditional and models where provided in a ready-made fashion. The two conditions are explained in chapter 4, which also reports the results.

In the final experiment the intervention was redesigned once more, based on the results of the previous intervention and implemented at four schools. The results of this phase are divided over chapter 5 (Study 3) and 6 (Study 4). Chapter 5 reports the quantitative results and analyses at school level. Chapter 6 describes the micro analyses on the basis of video-analyses. Finally, the results of all the chapters are integrated in chapter 7, leading to a comprehensive conclusion.

Some of the separate chapters have been, or will be, submitted to international journals. Some repetition will therefore be inevitable. In addition, in the mixed British-American journal context, spelling may not be consistent in relation to the thesis.

2.

Let the video be your guide: A case study of video-based design research*

Abstract

In this article the iterative process of a design-based research project using video as one of the data sources will be reported. During the iterative design and implementation processes video recordings of teachers and students were used to provide guidance through the practical and conceptual changes. The video was an indispensable data source. Without it there would have been no possibility of ‘seeing’ how the curriculum project was enacted nor what the explanations for several results based on other data might be. We explain how our video data guided our academic analysis at three levels, the baseline level, the methodological level and the meta-level. With hindsight we are able to 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. Through the use of video data we attempted to find an answer to questions of codified knowledge in knowledge-rich workplaces, simulated in vocational education. On the basis of our research experiences we conclude that video observations are indispensable if our aim is not only to improve theory and practice but also to reflect on the design of the method itself; especially if design research is regarded as open-ended, and the agency of participants is valued.

* This chapter will be submitted as an article.

Introduction

This study reports on the iterative process of a design-based research project using video as one of the data sources. The overall research question of the project was: *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?*

During the project, between 2005 and 2010, six schools with over 30 teachers and 200 students were studied. More than 100 hours of video data were gathered[2]. In what follows a post hoc analysis of video data use is described with the aim of determining the value and role of video in our research; thus showing "how we came to know" (Goldman, 2007, p. 29). The research project was design-based (Barab & Squire, 2004; Shavelson, D.C. Phillips, Towne, & Feuer, 2003; The design-based research collective, 2003), started with the design of an educational curriculum project and ended with an experiment at four schools. We collected data on seven schools in three stages over three years. Figure 2.1 shows an overview of the research time-line.

As is often the case with this kind of research many changes and reorientations were made along the way. We had to take design decisions before and during the implementation of the intervention (Cobb, Zhao, & Dean, 2009). At the beginning of the research project there was little experience in the Netherlands concerning research in workplace simulations in preparatory senior secondary vocational education (VMBO)[3], and no guidelines for video research in the learning sciences had yet been formulated (Derry et al., 2010). During the iterative design and implementation process video recordings of teachers and students were used to guide us through the practical and conceptual changes. In addition, video helped us develop our theoretical framework and guiding principles (Terwel & Walker, 2004).

With hindsight, the use of video played a significant role in that it guided research development at three levels. Starting with educational practice, video helped us to see and understand how the designed curriculum project worked in the classrooms. We call this the baseline level, since actual classroom practice was the unit of analysis. The designed educational intervention could be (re)viewed

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[2] This is an estimate since almost all video was digital and compression methods have changed, it is hard to calculate the actual hours of classroom footage.

[3] Preparatory senior secondary vocational education is the official English translation used by CEDEFOP for Dutch VMBO. It is pre-vocational education for 12-16 year old students. About 60 % of Dutch students attend this type of education. VMBO was introduced in 1998. From her onward we will use VMBO.

in action. The video data were therefore the visual tool for the primary analysis. In our case it supported the analysis of how the teachers guided the students and how students' understanding developed. The second level was methodological. At this level the video informed us how the implementation and methods developed within the separate stages and over the different stages. We divided this level into two sub-levels. The first concerned the way in which our intervention changed through the agency of the participants within one stage, as as well as how the video data through the stages showed our intervention changes from one stage to the next. The second data sub-level describes how the type of data changed and thus the type of analysis. Informed by both the baseline and the methodological level, our perspective also changed. This was visible at the meta-level. The video data itself changed over time. From an intensive and close look at a few participants it developed into a more distant view of many participants. In other words, not only had the method changed but our view of what we actually needed to know for answering the main research questions had also shifted. In the following sections we will address each level in greater detail.

The theoretical framework will be followed by a discussion of the three research stages (the baseline level). Next, we will take the reader through several changes of the intervention design and the methodological approach during the research project (the methodological level). Then, we address the question of how we adjusted our perspective (the meta-level). The following questions will be answered for each level:

a. What was the value of the video in this design research?
b. To which adjustments did the video data lead?
c. How were these changes visible in the video data?

Finally, in the discussion, the answers to the questions will be compared to the challenges formulated by Derry et al. (2010), especially those on the selection and analysis of video research in the learning sciences.

Theoretical framework and method

In vocational education students both design and construct real products in collaborative groups. Problem that need to be solved arise in the design process as well as in the actual construction. Models can be used to anticipate possible problems and their solutions. For example, on the basis of a model angles can be calculated in a drawing to determine how pieces of steel should be sawn off, rather than by trial and error only to find that the steel parts cannot be put together. Here the formula used to calculate the angle functions as an orientation tool.

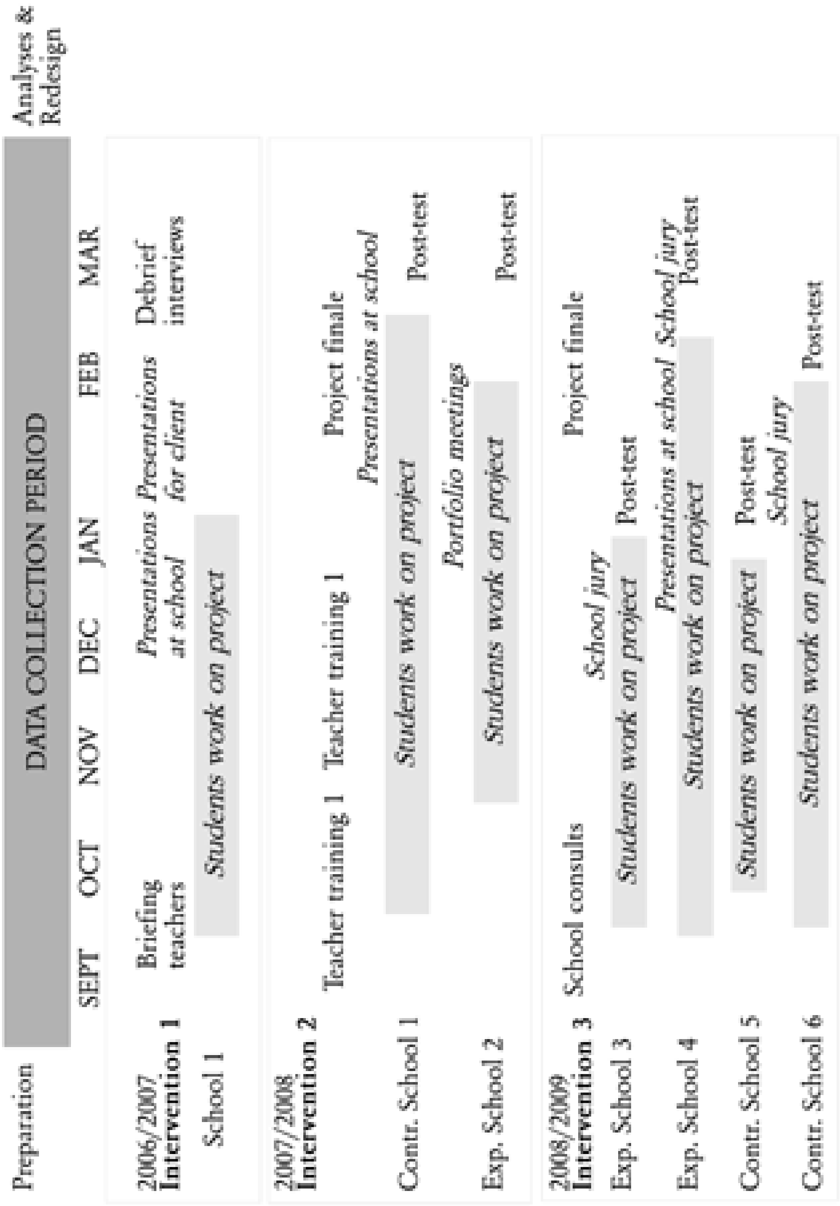

Figure 2.1 Time-line of the research.

By collaboratively reflecting on, and improving the production process group members learn to understand the mostly tacit rules and codes of the workplace as well as the hidden knowledge it involves. Models (as prototypes) could function as tools of communication and focus on the anticipated production process and thus help students think ahead and (collaboratively) reflect on their own process (Van Schaik, van Oers, & Terwel, 2010a; Tuomi-Gröhn, 2003).

The challenge to schools lies in formulating assignments that are meaningful for the students and realistic for their future work (Tuomi-Gröhm & Engeström, 2003; Volman, 2006). At the same time, such assignments should also result in highly qualified learning outcomes that enable students to recontextualize and translate their knowledge and skills from the classroom to the workplace and vice versa. Guile and Young (2003) suggest knowledge-rich workplaces to support the recontextualization of situated knowledge into codified knowledge.

The important role of the teacher(s) in our project, namely guiding the students in knowledge acquisition and practical understanding, also includes introducing students to the mathematical practice of modeling. It is the teachers' role to identify what is 'mathematical' in the practice of the workplace, to recognize the emergent need in students for mathematical tools and relate such need to the practice of (mathematical) modeling (Van Oers, 2001). Providing models alone is not sufficient to understand the use of models as tools; rather, conditions should be shaped that focus "… on the hidden rules and assumptions in the tools." (Van Oers, 2001, p.81). Therefore, the guidance of the teacher should promote this understanding by helping students co-construct the meaning of the models. Put differently, it is the teacher's role to "… maintain connections between the curriculum-based goals of activity and a learner's existing knowledge, capabilities and motivations" (Mercer, 2002, p. 143). Research has shown that the instructional strategy of guided co-construction may lead to a better understanding of mathematics and modeling than a strategy based on models that are simply provided (Doorman, 2005; Terwel, Van Oers, Van Dijk, & Van den Eeden, 2009; Van Dijk, Van Oers, & Terwel, 2003).

From the theoretical framework above four guiding principles were formulated for the design of innovative practices. First, the student assignments had to be meaningful; that is, resembling workplace tasks related to students' possible future vocations. Secondly, assignments had to be complex enough to enable students to learn more than just vocational skills. Real workplace activities could increase the need for specific knowledge and skills and subsequently provide opportunities for learning. Following Guile & Young (2003), such a workplace may be characterized as a knowledge-rich workplace (p.73). They are assumed to engage students in meaningful activities and at the same time promote subject matter learning (such as mathematics; see Kent, Noss, Guile, Hoyles, & Bakker, 2007). The product to be constructed should be new to the students and challenging in such a way as to require the creation of models, plans and calculations. Such a process might lead to a recontextualization of previously learned codified knowledge in a new situation. Third, the students had to collaborate on the cooperative construction, as well as there mutual communication while focusing and reflecting on their models. Fourth, the schools had to be adapt and adjust the intervention to their local conditions. The curriculum project therefore needed to be adjustable while the core of the assignment goals had to be maintained.

For our study we designed an educational curriculum project for vocational education. Students had to design and construct a tandem tricycle for approximately five-year old elementary school pupils. Teachers were to guide their students in the design and construction process. For about 10 weeks students, together with the teachers, worked at this construction task in groups of three to five in large school workplaces, while solving problems and gaining new knowledge to get the work done. We closely studied the way in which teachers guided the students and tested the knowledge gained during that process. The data came from three separate stages: at the first stage one initial design of the curriculum project was implemented at one school and qualitatively analyzed as a case study (Van Schaik et al., 2010a); the curriculum project was redesigned on the basis of the results. The following two stages consisted of two experiments. In these experiments the redesigned curriculum project was tested, at two schools and four schools respectively. At the latter stages we collected video observations in addition to test data on knowledge, understanding and student characteristics.

The approach of the complete research project could be characterized as design-based (Barab & Squire, 2004; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; The design-based research collective, 2003). This methodological approach needs further explanation.

Since our theoretical framework had a Vygotkskian foundation, according to Bell (2004), the project could be labeled cultural psychology design-based research which "… .. attends to the local cultural–historical foundations of development and learning as it is promoted and transacted through patterned interactions between individuals and artifacts" (p. 247). As the teachers were constantly involved in the development of the intervention together with the researchers the concept of mutual appropriation may be the proper way to understand our iterative design process (Downing-Wilson, Lecusay, & Cole, in press). For Engeström (2009) acknowledging the role of the teachers as actors who in the end shape the intervention is one of the characteristics of research based on a Vygotskian foundation. In addition, since our aim is also to "… generate *intermediate* concepts and solutions that can be used in other settings as tools ..." (Engeström, 2009, p. 321, italics added), and given that such solutions are not known ahead of time, our methodology could be characterized as a formative intervention.

The reason for using a video approach, not only in the case study but also in the two experiments, was that we aimed to analyze both the students' microgenetic learning trajectory and the development of the intervention (cf. Mercer, 2008). Using video in addition to to other forms of data, it was possible to identify "the changing participation of the students in group interaction" (Erickson, 2006, p. 181).

All in all we collected more than 100 hours of video data over the three research stages. The video data consisted of classroom data (including interviews supported by classroom footage) and co-design data (including member checking, cf. Stake, 1995).

After collection of the observation data, we looked for interactions on the way students used information and mathematical models and how the teachers assisted them in the use of such newly acquired tools when solving the problems they encountered. Three cameras were installed in the classroom: two fixed cameras and one hand-held camera. The fixed cameras recorded continuously while one of the fixed cameras also recorded the audio that was captured by means of a wireless microphone attached to the teacher. The third hand- held camera was operated by one of the researchers (always the same person), aiming to capture those interactions in which students and teachers together, or students by themselves, solved problems (for a more detailed description see van Schaik et al., 2010a; Van Schaik, 2009). In addition, we video-recorded the interviews with students and teachers held shortly after each observation, in addition to the training and participant-checking sessions.

The baseline level: The research narrative

In this section we describe the research narrative, which may be considered a brief summary of the overall research project processes. More detailed descriptions of the findings can be found in the reports of the separate studies (Van Schaik, et al., 2010a; Van Schaik et al., 2010b; Van Schaik et al., submitted a; Van Schaik et al., submitted b)

The research project started in November 2005 and lasted five years. The collaboration with teachers and schools started early in 2006 and is still continuing. After having defined our design principles (see above) we created two possible assignments for students. We proposed these to the first school and asked the teachers if they expected the students to be able to complete the

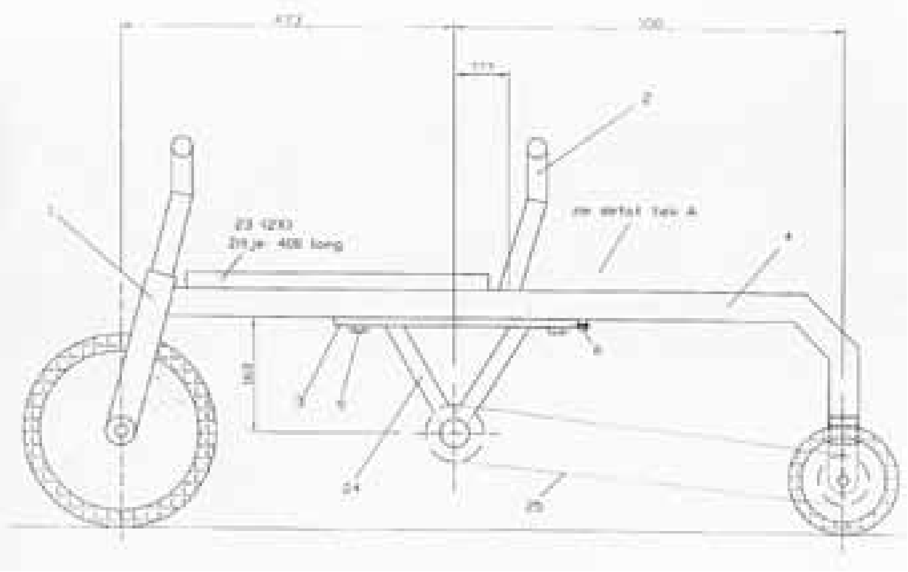

Figure 2.2 Technical drawing of students' design drawn by the teacher

assignments, and requested them to indicate which one they thought more feasible with regard to finishing the product and the opportunities for modeling. Together with the teachers we selected two construction assignments to be tested in a case study: a bicycle race game and a tandem tricycle. Each of these required about eight weeks (the duration of the school term), with at least a daily two hours' work on the assignment. After the case study analysis the tandem tricycle assignment proved to be more knowledge-rich, and was redesigned for the next interventions. An experiment was conducted at two schools and both the qualitative and quantitative data were analyzed. Next, based on the findings the curriculum project was redesigned, followed by a second experiment at four schools. In the next sections we report on the role of the video data in the outcomes of these three stages.

Case study

Initially, we went to the school with some propositions of assignments. In the assessment process two co-designed curriculum projects were studied. The projects took about eight weeks in the autumn of 2009. During that time we collected video data on the projects as enacted in the classroom and on interviews with students (n=15) and teachers (Van Schaik et al., 2010a; Van Schaik, 2009). In the latter video-stimulated interviews (Clarke, 2002) participants were shown video images of their own activities and were asked what happened. In the final interviews we had the students reflect on what they had learned and how the assignments were different from the ones they were used to. Teachers were asked what they thought the students had learned and how these assignments could be improved.

The analysis of the observational and interview data provided evidence that the knowledge in the simulated workplace remained situated. That is, the knowledge involved was not general in the sense that it could be recontextualized by the students to other situations or contexts. In addition, the knowledge and models were provided by the teacher as ready-made solutions (Figure 2.2 shows an example of a construction drawing by the teacher). In Video 2.1 examples from the video data supporting the findings are collated.

»ε Video 2.1 Video samples supporting case study findings[4,5]

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[4] »ε (ε from extra and the Greek word ε□δον, to see) indicates an extra video sample which can be found at http://mvsjtbvo.video-research.eu after registration.

[5] Informed consent was obtained from the parents by the schools, as the researchers only had contact with the schools.

After this first data analysis we went back to the teachers for a participant member checking. In this session we checked whether the teachers agreed with on our analysis, and how the curriculum project could be improved. Two practical issues were raised by the teachers. First, they suggested that, since one of the assignments (the bicycle race game) did not get finished, it would have been too difficult for the students to design a double transmission object (for the game to work, students had to come with a solution for at least two transmission problems). This was in line with our observation that the teacher provided the ready-made models. As one teacher put it:

Excerpt 1

Teacher: ... let alone [the students] having to make a construction drawing. They are simply not up to it. The drawings and sketches they make do not resemble a technical drawing. It think it is my job to make a drawing they can work with.

Secondly, the 'client' for the race game was a former teacher of the school and may not have been 'real' enough (the client for the tandem tricycle was a elementary school head). The tandem tricycle was regarded the better assignment to continue with. The main improvement in the project, according to the teachers, would be a better integration of the subject matter classes and the practice workplace. However they did not offer any suggestions as to how such integraton might be implemented.

We continued our analysis with the insights from these data and designed the next version of the curriculum project. We selected the tandem tricycle as the assignment and developed a guide for the teachers based on the experiences in the first case study. For the students there was one change: the product to be constructed should be a prototype for a contest. This would justify teachers in asking students to reflect on their process and production, using and exploring knowledge and models from science and mathematics. Thus, integration of subject matter classes might be established.

First experiment

In implementing the first project experiment at two schools (n=65) we received help from an experienced teacher trainer, who was specialized in mathematics. He led the sessions with the teachers, during which we co-developed and implemented the curriculum project at each school in accordance with the research conditions to which they had been assigned. We had an initial meeting with all participating teachers of each condition separately, during which the project's significance for the students was explained, while the opportunities for modeling, based on the first study, were highlighted. During this session we used clips from the case study video data to illustrate what the intervention might look like. We asked the teachers how they thought they might implement the intervention. Their suggestions were worked out during the summer vacation, resulting in two separate programs, since we planned to conduct an experiment in a pretest posttest control group design. This was to mirror the difference between the conditions to be enacted: teachers in the control condition would provide models to the students, whereas teachers in the experimental condition would guide students in collaboratively constructing the models themselves. It should be noted that schools were assigned to the conditions depending on their current pedagogical practice, which we determined during school visits and subsequent meetings. The teachers were allocated to the condition that best fitted their customary approach to teaching (providing or guiding co-construction).

The implementation took place in the autumn and lasted 8-10 weeks. Each school fitted the curriculum project into their existing year planning, which explains the difference in duration. The teacher trainer visited the schools twice during the implementation to consult with the staff. In addition, we had a collective session for each condition half way during the implementation. Video data was collected in the same fashion as for the case study: three classroom cameras and video-supported interviews with both students and teachers. Moreover, we pre-and posttested the students on knowledge and modeling, and collected test data on their initial characteristics such as vocabulary, general intelligence and personality (Van Schaik, Van Oers en Terwel, 2010b).

The quantitative analysis of this intervention showed no difference between the conditions with respect to scores on the posttests on knowledge codified from the disciplines (maths and mechanics). However, as rated by modeling experts, the students in the experimental condition produced better models of their products. Interestingly, analysis of the video data showed that the students' models (i.e. the construction drawings) disappeared during the process of construction, and were no longer visible in the observations. Video 2.2 shows typical of week 3 and week 6 sequences at School 2, starting with week 3 sequences with students working on, and using their drawings, followed by week 6 sequences without drawings.

»ε Video 2.2 Typical week 3 and 6 sequences at school 2

Again we went back to the schools with these analyses of the test and video data to check whether our initial sense of what had been going on was confirmed by the teachers. These sessions were very different at the two schools. The teachers in the control condition, again, were very constructive and confirmed our first analysis. Their main point was that students should be taught how to draw and design on separate occasions, since they were patently incapable of doing that:

Excerpt 2
Teacher (control condition): [I] don't ask them to do the drawing themselves [the technical design model], because they simply can't.

The teachers in the experimental condition intimated that they had been skeptical from the start, since they thought students needed more guidance. Looking back at the video recordings of the training sessions from the start of the project onwards, we could confirm that the teachers had in fact been skeptical. However, at that time they did not express their skepticism verbally. Video 2.3 shows shots of this training as well as the teachers' body language and some of their utterances.

»ε Video 2.3 Shots of the teacher training session

The classroom video showed that the guidance students received had in fact been minimal, focusing on assignment planning and finishing.

All in all, the test results did not show any significant differences between the conditions; the video data did however. We concluded that in spite of the small amount of guidance students received in the experimental condition, their performance was better on modeling due to the focus on the process and the use of models as tools for communication and orientation (Van Oers, 1988; Van Schaik et al. submitted a).

On the basis of our previous experiences we decided to design a new series of separate prototype lessons on designing. The only difference between the conditions was the way the lessons were enacted: in the control condition they were planned ahead, whereas in the experimental conditions the lessons were taught ad hoc or more or less 'on demand'. The student assignment remained the same.

Final experiment

Following the same time schedule as in the first experiment, we selected four schools (n=87) in the spring and explained our plans, again with the use of video. We did not organize any collective training sessions, nor any teacher trainer help, since the program for the schools was strict. However, it was the teachers that chose their own method of implementation. This meant that, apart from fitting the programme into their schedules, they had to find a way of implementing the prototype lessons and connect them to the practice workplaces. In two cases it was the teacher that was the connection: he taught both practice and the design lessons. In the other cases the prototype lessons were planned during mathematics periods. Schools were assigned to a condition in the same way as in the first experiment, and the implementation again took 8-10 weeks. The collected data was similar to that of the first experiment. The video observations differed in frequency since we had more schools to attend. We therefore focused on the crucial weeks in the process: the beginning, the period between weeks 3 and 6, and the end.

This experiment was analyzed in two studies: one was more quantitative, the other more qualitative in nature. From the quantitative study we found that, as in the first experiment, there was no difference in knowledge between the conditions as measured by the posttests (Van Schaik, Terwel, & Van Oers, submitted a). Two schools scored higher on the posttests; however the difference with other schools was not significant, while the schools were not in the same condition. We subsequently conducted a second study to analyze the actual differences in conditions and in processes between the four schools looking for an ex post-facto explanation for the different learning outcomes (Van Schaik et al., submitted b). From the analysis of the within-school enactment and across-school comparison it was clear that two schools differed from the other two in the way models were used in practice workplaces. At Schools 4 and 6 the models remained visible until the end of the process, whereas at Schools 3 and 5 the models seemed to disappear once the actual construction of the tandem tricycle had begun (see Video 2.4 for a comparison of presence of drawings in week 6). Moreover, at Schools 4 and 6 far more interaction on the models was found in the observations. Teachers and students used their models as tools for orientation and communication.

»ε *Video 2.4 Presence of drawings in project week 6 at Schools 3 and 4*

At the baseline level the video was one of the data sources that led to our conclusions in the separate studies. In other words, the baseline level described the findings from the video data. At the methodological and meta-levels we looked for the changes in the video and examined their correspondence with the methodological and theoretical changes.

The methodological level: adjustments to the intervention and method

Before we continue and discuss the way video informed the design process we need to explicitly describe the changes in the curriculum project and method

Table 2.1 Development of design and shifts in perspective informed by video

	Issues on Bbaseline level	Implications for **next** phase Methodological level		Shifts on Meta-level
		Intervention sublevel	Data sublevel	
Case study	- Knowledge remained situated - Models were provided - Client needs to be real - Integration subject matter*	- Guidance and instrument for teachers (with suggested lessons) - Prototype competition	- More distant video approach (more schools, more students) - Also quantitative data	Reflection on production process may lead to recontextualisation (prototype)
First experiment	- Drawings disappear during process - Models in experimental condition are better - Minimal guidance on theory and modelling* - Little or low quality student drawing*	- 'Prototype lessons' (explicit attention for models) - Backward engineering models	- Focus of observations around week 3-6	Models should be tools like professional designers
Final experiment				
a) First study	Better performing schools have: - Teachers with academic background - Higher teacher-student ratio		- Deeper qualitative analyses needed	'Disciplined perception' should be promoted (vocational & academic)
b) Second study	At best performing schools: - Explicit attention for disciplines - Models as tools the entire process	Parameters for assignment and teacher guidance: - Potential theory-rich assignment - Teacher student ratio - Teachers' background - Use modelling as core - Explicit reflection on disciplines		Integrated pedagogics with modelling as core activity.

* found in interviews or member checking

based on video information. The first column in Table 2.1 describes the issues that emerged after the first analysis of the video data.

The implications of the video analysis are shown in the second and third columns of Table 2.1. Divided over two sub-levels, both the adjustments of the intervention and the method are shown. For example, the second cell of the first row (Case study) describes how we redesigned the curriculum project for the first experiment. The theoretical shifts are displayed in the fourth column, to which we return in the next section.

The implications on the methodological level were results of the analysis at baseline level. Put differently, analysis at the first level led to adjustments at the next level. However, the adjustments became visible in the data after the fact. Only by reviewing the video of the whole project could the implications as planned after one stage be (re)viewed in the data of the next stage.

At the intervention sub-level, the main difference between the first experiment and the case study was that the assignment had been turned into a prototype contest. This was an attempt to acknowledge the problem of the situatedness of the knowledge involved, and the need for ecologically valid situations for the students. As a consequence, if was not enough for students to construct a working tricycle, they needed to have a production plan. In addition, a contest solved the problem of having 'real clients': the prototype jury panel was in fact the client. In order to stimulate the integration of subject matter into the project, an instrument was developed whereby possible references to mathematics and science, derived from the case study, were incorporated as examples. For example, for the teachers the instrument predicted that the students would most probably encounter the issue of how to propel the tandem tricycle. This provided an opportunity to bring in theoretical knowledge on transmission, about which an example lesson was provided. In addition, two teacher training sessions were organized, led by a teacher trainer who, in addition, was available for on-the- spot coaching.

The three-camera approach was maintained (see Figure 2.2 for a schematic overview and Video 2.5 for a panoramic video overview of the simulated workplace), with the hand held camera focusing on the possible modeling interactions of all students, according to a protocol based on the experiences in the case study. This resulted in video data that showed the practice process for the entire classroom rather than for a couple of subgroups in the case study. By way of example, in the case study the hand-held camera followed two subgroups in one observation, whereas in the first experiment the same camera switched back and forth between four subgroups. As a result it became clear what the routines in the workplace were. Again, students and teachers were interviewed during and after the project with the help of video data from earlier observations, although less frequently

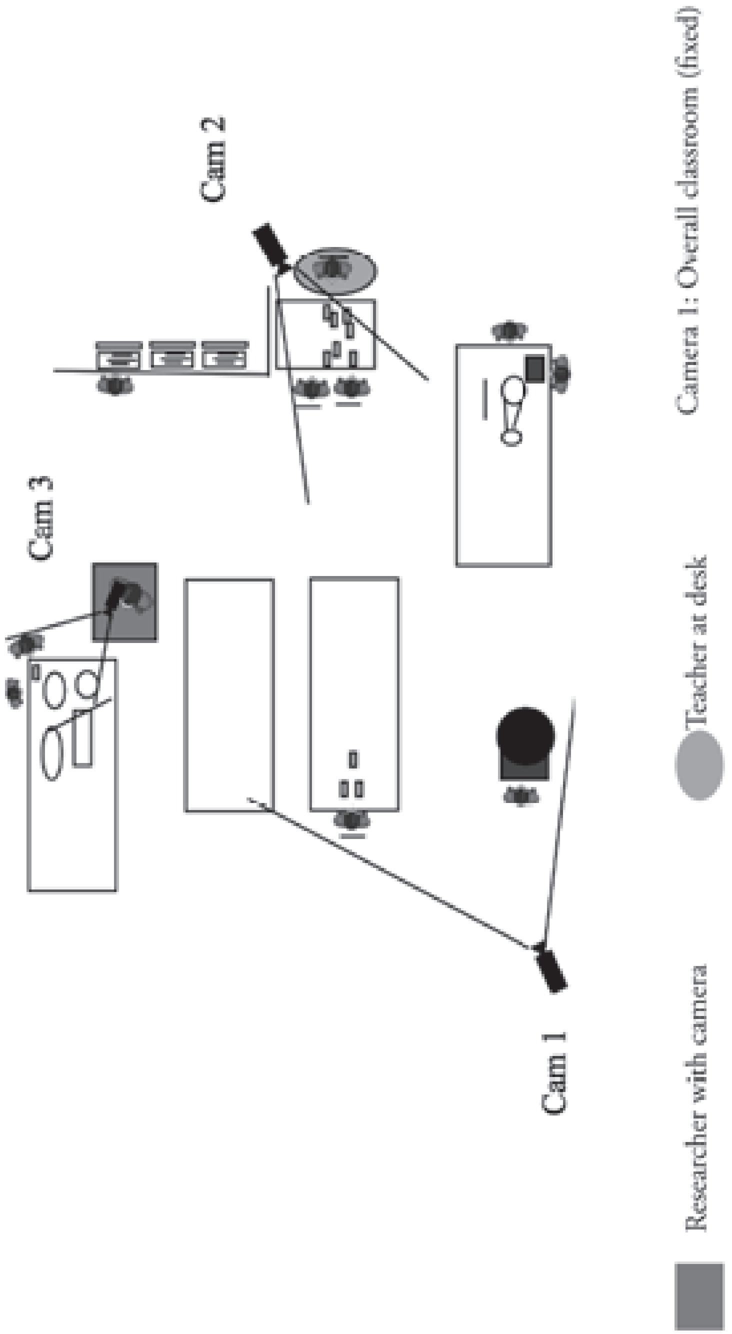

Figure 2.3 Video data collection in the classroom

than during the case study. The teacher training sessions were recorded as well. As in the case study, member checking was done afterwards.

»ε Video 2.5 Panoramic overview of simulated workplace

Compared to the first experiment only two significant adjustments were made to the second. First, the teacher guidelines of the first experiment were converted to a manual (Van Schaik et al. submitted a). Second, prototype lessons were developed and adapted for the two conditions. Both adjustments were intended to keep the students' drawings present during the entire process and to ensure moments for modeling guidance. A smaller adjustment to keep models present during the process involved the students' task to reverse engineer their products: the final prototype also needed to have a model on paper that resembled the actual construction.

In the second experiment the frequency of the video stimulated interviews per school was further reduced and only a single school training session organized. Earlier studies had taught us that the crucial moments in the students' design and construction process lay between weeks three and six. Since these were the weeks when the drawings tended to disappear the research focus shifted to the video observations.

After the first study of the second experiment we concluded that a qualitative analysis was needed to gain a better understanding of classroom processes. The quantitative data alone provided no clue to an explanation as to why there were only small, non-significant, differences. Subsequently we conducted a multiple case study, taking each of the schools involved as an individual case (Van Schaik et al. submitted b). With the conclusions of this study we would be able to close the cycle and return to the teachers with the implications for their practice.

The results from the video analysis at baseline level were the basis for the change in the intervention. In addition, the video was also used to provide information on the efficacy of our method. That is, it could show how students and teacher reacted to the more practical aspects of the assignment, as well as to the video cameras and the training sessions.

In the first case study, we observed not only that the tricycle students were very motivated, but also that other students who did not win the design contest were less motivated. We also found that the race game students lost their motivation a little due the teacher's role as client. As a result, the contest was continued as part of the next intervention, with the jury as real users: five-year old children, a school head teacher and a toy company.

The use of video cameras is intrusive to some students. Fortunately however,

Table 2.2 Hours of video data in the three phases

	video (hrs)	Schools	Students
Case study	30	1	6
First experiment	40	2	65
Final experiment	30	4	87

most students do not seem not to have any problem with it. At one point, early on in the project's case study, a student can be seen dancing and rapping in front of the camera. He asks the researcher: "Will I be on MTV?" The same student can be observed a few weeks later listening to the teacher in an interaction and apparently unaware of the camera, which was only a few metres away (see Video 2.6 for the two different reactions on the camera of one student). Although the cameras were obviously noticed, when the students were really involved in their tasks for the assignment they seemed to be forgotten. From this we learned to set up the cameras for the tests as well, to enable students to get used to it and reducing the amount of skylarking during the actual design and construction process.

»ε Video 2.6 Students' camera awareness

In addition, we noticed after a training session during the first experiment that some teachers showed a certain reluctance to accept that the intervention might work and thought that the project for students was too 'open' (see Video 2.3). In the next experiment we therefore created a more detailed lesson plan, tuned to the condition.

The major change in the intervention and method may be characterized by stating that we moved from close co-development with a few teachers to more distant cooperation with more teachers. From a single assignment, the intervention gradually developed into an almost ready-made lesson plan, while from a case study approach following two subgroups, the method became more integrated using both qualitative and quantitative data. The methodological approach developed into a broadspectrum methodology, with the video data as the interlevel and intralevel connections between the different data sources.

The meta-level: shifting perspectives

An examination of the video data over the three stages revealed that the actual curriculum project as well as our method changed as a result of our intervention adjustments. Furthermore, the classroom process changed. At the same time the video data itself shows how our perspective literally shifted; in the sense of capturing changes from a somewhat narrow experimental perspective on a few students in the case study, to a much wider perrspective on many students.

From these intervention adjustments (to the curriculum project and the method) we already notice a growing insight into modeling in knowledge-rich learning environment. In the case study the research was still exploratory, whereas in the final experiment the focus was narrowed down to how the models functioned as tools in the design process. For example, we knew that between project weeks 3 and 6 students' drawings might fade into the background. It would therefore be useful to carry out observations at that point in the project (e.g.Van Schaik et al. submitted b). It is interesting in this respect to note the amount of video data we collected over the three stages. During the case study we collected about 30 hours of video, while the number of hours during the first and final experiments amounted to 40 hours and 25 hours respectively (see Table 2.2). The overall data included classroom observations, interviews and teacher sessions.

The amount of video data per school dropped form 30 hours to 20 hours, and eventually to less then 10 hours. The explanation for this is twofold. First, during observations our knowledge of what to shoot improved as our understanding of classroom and modeling processes improved. Second, as the research progressed the timing of our observations improved. Both explanations imply a shift in perspective.

A more abstract, less practical and observable shift took place in the evolution of the subsequent research questions and hypotheses for each study. A characteristic of design research is that it is "pragmatic as well as theoretical in orientation in that the study of function – both of the design and of the resulting ecology of learning – is at the heart of the methodology" (Cobb et al., 2003, p. 9). After our discussion of the pragmatic part, the question remains as to whether the theoretical shifts are also visible in the video data.

The last column of table 2.1 displays the shifts in our focus at the meta-level as derived from the video data. The theoretical development are best illustrated by the shifts in our research questions for each study. The research questios for each stage and study were:

For the case study: *Which teaching/learning processes occur in a simulated workplace using the concept of a knowledge-rich workplace, and what is the role of models and modeling?*

For the first experiment*: Do students in the experimental condition acquire more knowledge and better understanding in mathematics and science?;*

Do students in the experimental condition develop a better understanding of the use of models?; and

Do students in the experimental condition produce better models/drawings of their own products?

For the final experiment:

Study A:	*By designing a real product themselves, do students,guided in a co-constructive way, gain codified knowledge in mathematics and science and a better understanding of modelling?*
Study B:	*What was the actual teaching/learning practice in the schools and how did the schools differ, especially in how the models functioned as tools in the design process?* *Was the teaching/learning practice aimed at designing and understanding related to the disciplines, both the academic and the vocational?*

The shift from a more open, exploratory question to a more narrowed down question could ultimately be interpreted as an indication of development at the theoretical level. Although the questions in themselves do not reveal what exactly was learned from the video data, they do reveal a shift in perspective. Initially the focus is on the learning environment, the models and the teaching/learning practice. Next, the output comes into focus as well of course as the differences between the conditions. Finally, the teaching/learning process is made explicit (guidedco-construction) and the questions concern the functioning of the models as tools. These shifts are in line with the pragmatic shift at the intervention and method sublevels. For example, the assignment client was changed during the intervention to a prototype contest, justifying us to ask students to create final drawings. These were, in turn, our output measures. Prototype lessons were also developed, creating moments for teachers to instruct the students in using models as tools in other contexts. At the same time, at the method sublevel, output measures were incorporated into, and integrated with, the video analysis.

Additional theory was required, especially for the intervention adjustments. The work of Lave and Wenger (2005) was used to create the prototype contest, using their idea to the effect that (collective) reflection on the production process promotes learning in a community. Moreover, MacDonalds and Gustafson (2004) helped us understand the way models can function as tools in a design process and thus the need for a final drawing. Finally, the concept of disciplined perception (Stevens and Hall, 1998) constituted a new framework for understanding how teaching could enhance students' understanding and codified knowledge: how teachers could guide students in adapting the ways of examining and interpreting that are common to the disciplines (vocational and academic).

Not only did we learn when to look for what in a practical way, we also gained a deeper understanding of what we needed to know when collecting and analyzing video data. In short, video makes changes of perspective and insights visible over time.

From data to evidence at multiple levels

The main point of this study is to show how video data can guide a research project. Design research is developmental and emergent, that is, it designs and redesigns programs and interventions collaboratively with participants on the basis of outcomes and incidents that occur during the process. As a consequence, the data collected at each stage not only include information that serves to examine the effectiveness of the intervention, but also information that necessitates analysis at other levels. It follows that video is an indispensable data source. Without it we would not have 'seen' how teachers provided ready-made models, or how drawings gradually disappeared at the workplaces, or how the curriculum project was actually enacted.

In these pages we aimed to explain how our video data guide our academic enterprise at three levels.

For each level we provided answers to the following questions:

a. What was the value of the video data in this design research?
b. To which adjustments did the video data lead?
c. How were these changes visible in the video data?

From the baseline level, the video data helped us redesign the curriculum project and the method. As a result the analysis of video observations and interviews led to a number of adjustments at the methodological level. First of all the observation video data showed us how the interventions worked in the classrooms. Second, the video data helped us triangulate our findings with the participants, thus enabling us to refine our analysis. Finally, the video observations helped our training procedures and our planning layouts for participating schools. Restricting our range to quantitative data would have resulted in fewer insights into the school processes and a less implementable curriculum project in the two experiments. Moreover, some processes would have remained permanently hidden (e.g., disappearing drawings, types of teacher guidance) if our experimental analyses had been based solely on the test results. More specifically, the video data show that teacher-provided models tended to disappear during the construction process, and that teachers in the guided co-construction condition stressed the use of student drawings. Although the issues on which the adjustments were based were directly visible in the data, the adjustments that were actually carried out could be reviewed only after the redesigned intervention had been reimplemented. The present analysis as such is a triangulation of our design process after the fact, which would also have been impossible without the video data.

With hindsight we 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 project's research conditions (providing codified knowledge versus co-constructing) had not worked out as predicted in the context of knowledge-rich environments. On the basis of our workplace observations we were able to refine the design's guiding principles and conduct a replication study, which, as it happened, yielded basically the same answers to our main research questions. Further, the video data from students' and teachers' workplace activities enabled us to discover in the redesigned project that the design and use of the models differed for the various schools in. The data even enabled us to speculate about conditions that might be conducive to such situations. As a result, our attempts to find answers to our original research questions concerning the learning of codified knowledge in simulated knowledge-rich vocational education workplaces obviously needed theoretical refinements that no longer focused on determining the 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) and the way this process was guided by discussions and appropriately tuned-in instructions by an expert (teacher). It is our contention that a decade of studies on the issue of providing versus co-construction has reached a new stage with detailed video-analysis. Such studies should in our view be defined as studies of providing in the context of guided co-construction and as studies of the ways co-construction may support the meaningful use of tools and codified knowledge in students' problem solving when engaged in processes of construction and design.

In addition, the video data functioned not only as our source for analysis or as a tool for interviews and participant member checking, it also brought the intermediate concepts and solutions (Engeström, 2009) back to the schools. For example, when we showed the observation videos to the teachers, one of the effects was that the video data informed the teachers of their own practice and our perspective on it. If design-based research is to improve theory and practice, and if it is to be regarded as an open, non-linear process with acknowledgement of the participants' agency, then relaying the insights to the workshop should be a part of the research. The Vygotskian notion of double stimulation (Engeström, 2009) could thus be extended to triple stimulation: The first stimulus in the formative intervention would constitute the problem, the second stimulus the tool (intervention program) as adapted by the participants, the third the intermediate concepts and solutions brought back to the participants. The cycle would thus be closed and, by way of a next step, a new problem might be formulated and research continued.

We believe to have demonstrated that video is not just a rich data source. We also believe it to be indispensable in design research if our aim is to improve theory and practice and, in addition, to reflect on the method itself. Especially if we regard design research as open-ended and value the agency of participants.

3.

Towards a Knowledge-rich Learning Environment in Preparatory Secondary Education*

Abstract

In this case study an novel educational programme for students in preparatory vocational education was studied. Our research questions were: (1) Which 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? The curriculum project consisted of design and construction tasks. The students were collaboratively involved in the process of designing a tricycle for a real customer. This real-life activity creates opportunities for students to develop and use models, which can be used in more than in one context. In our case study we explored how the teachers deal with the students' explicit and implicit need for knowledge and skills. The main findings are that teachers more often provide this knowledge, rather than guide the students in reconstructing it, and towards the end of the project, knowledge tended to remain situated.

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Learning in preparatory vocational education

Over recent decades, Dutch preparatory senior secondary vocational education[6] (VMBO) has gone through different radical changes. Traditionally, this education was mainly focused on training technical and vocational skills. However, in the 1980's, theory-based learning became the focus in VMBO. Neither of the two approaches was satisfactory. The first (practical) approach could not optimally stimulate the broad development of students, the second approach was often too difficult or resulted in meaningless mechanical learning.

Within the European Union and elsewhere it is recognised that in order to prepare students for the demands of the future, they should obtain competencies that cover both broad general knowledge as well as technical skills (Cedefop, 2009; Commission of the European Communities, 2008). However, there is an ongoing debate on how to connect formal learning and learning in the workplace (Billet, 2003; Griffiths & Guile, 2004; Guile & Griffiths, 2001; Tuomi-Gröhn & Engeström, 2003).

By observing current VMBO classrooms, and interviewing students and teachers, a new approach to learning in VMBO has emerged. As an attempt to improve the relevance of the knowledge and the effectiveness of the transfer to the workplace, like in other countries, a reform is taking place in VMBO schools (Guile & Young, 2003). Students and teachers learn together while they work on products for "real" customers. The basic assumption behind this approach is that learning of subject matter knowledge and vocational skills can be integrated in authentic workshop practices. However, knowledge, for example knowledge about modelling or knowledge gained in mathematics education lessons, is often not used for problem solving in a workshop setting. Students often do not recognize the relation between theory and practice, which results in a reduced learning outcome and lack of motivation on the part of students. The challenge for schools is to provide assignments that are meaningful for the students and realistic for their future work (Volman, 2006). At the same time, those assignments should also result in highly qualified learning outcomes that enable students to recontextualise their knowledge and skills from the classroom to the workplace. Teaching should support a meaningful link between both practical problem solving and subject matter knowledge (Van der Sanden, Terwel, & Vosniadou, 2000).

Real workshop activities could increase the need for specific knowledge and

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[6] In the following paper, we use the Dutch acronym (VMBO) for preparatory senior secondary vocational education. VMBO is Dutch secondary education for students aged 12-16 years that prepares them for senior secondary vocational education. 60 % of all Dutch students aged 12-16 years attend VMBO (Maes, 2004).

skills and subsequently provide opportunities for learning. Following Guile & Young (2003), such a workplace can be characterized as a "knowledge-rich workplace" (p.73). Knowledge-rich workplaces are assumed to engage students in meaningful activities and at the same time promote subject matter learning (like mathematics, see Kent, Noss, Guile, Hoyles, & Bakker, 2007).

From practical experiences in preparatory technical education it is known that models and modelling play an important role in these learning processes. Learning to model is a key issue in modern practical and technical education, where students have to design and create a fire basket, a trike or a wine rack (Van der Sanden, Streumer, Doornekamp, Hoogenberg, & Teurlings, 2003). Models can be used in practical production and in vocational and mathematical learning.

By designing a technical product with the help of the teacher(s), students can learn to understand technical and scientific rules and principles, and their mutual relations as represented in models. It is expected that knowledge-rich workplaces (Guile & Young, 2003) have the potential to be integrated learning environments which can produce meaningful learning processes that result in high quality learning outcomes (see also Nijhof & Nieuwenhuis, 2008).

Adopting the idea of knowledge-rich workplaces for teaching models and modelling practices in VMBO, however, raises a number of questions. Is it really possible to base knowledge and skill acquisition in VMBO on this approach? What is the quality of the learning outcomes (in terms of deep-level understanding or flexible application)? How should learning processes, embedded in practical work, be managed by a teacher? In our research project, some of the questions related to the guidance of learning processes in knowledge-rich workplace settings in classrooms are addressed. In particular, how teachers assist students in acquiring necessary skills and knowledge regarding the design of useful construction models for the accomplishment of their assignment was explored. As a first step, a case study was conducted in which teacher - student interactions in a knowledge-rich workplace setting were closely observed. In this case study, the theoretical framework and the concept 'modelling' will be first be further described. Second, the research methods and the way in which the curriculum project was developed and implemented in the school will be described. Next, a qualitative analysis of occurring patterns is conducted addressing the following specific questions: *which teaching/learning processes occur in a simulated workplace using the concept of a knowledge-rich workplace, and what is the role of models and modelling?*

Models and modelling in knowledge-rich practices

Focusing on modelling in teaching-learning processes requires a further explanation of the cognitive functions of models, of how models and modelling are conceived, and of how models can be meaningfully integrated in the teaching process.

This study draws mainly on the learning theory of L.S. Vygotsky and the subsequent development of this theory (Kozulin, 2003; Rogoff, 1990; Van Oers, Wardekker, Elbers, & Van der Veer, 2008; Wertsch, 1985). Equally important for the framework is the concept of a knowledge-rich learning environment from Guile & Young (2003), which refers to environments where students work and learn and are able to acquire "broader forms of knowledge and skill" (p. 73).

This theoretical background implies that learning is seen as a process of qualitative change that results in enhanced possibilities of participation in sociocultural practices (Van Oers & Wardekker, 2000). Likewise, learning as micro-genetic development contributes to enculturation into a community of learners (Brown & Campione, 1994; Lemke, 2000; Rogoff, Matusov, & White, 1996). As for learning in a workplace setting, such a community is best characterized as a *community of practice* (Lave & Wenger, 2005). Ideally, in these communities of practice, learners are actively involved in meaning-making activities, and they use tools and artefacts to solve problems, as well as to communicate with each other and with others outside the community.

Furthermore, from neo-Vygotskian socio-cultural theory it follows that in the accomplishment of activities, new goals and needs may emerge that drive us to construct or adopt new tools (see for example Kozulin, 2003; Saxe & Guberman, 1998). By participating, students encounter new goals that encourage them to appropriate new practice-related tools like concepts, symbols and models (Gravemeijer, 2002). If those tools connect the learners with each other and/or with other perspectives, they can facilitate the (re)construction of subject matter knowledge.

Models can be seen as structured tools that facilitate problem-solving activities. Models have two core functions: orientation and communication, which are not mutually exclusive. Orientation, according to Gal'perin (1976, in Van Oers, 2006), is an essential moment of cultural action. A model, according to this point of view, is a cultural tool for orientating on actions to be performed (Van Oers, 2006). Like a map helps to plan a trip, the model gives direction to a person's activities. As orientation is a cognitive activity, it includes valuation, producing information, planning, predicting, etc. As tools for communication, models foster the distribution of individual ideas and meaning across the community. When, for example, students work together on the construction of a tricycle, the drawings, plans and ideas (i.e. the models) are used to plan the process, predict problems and discuss the final design. The models give direction to the actual design and the planning of the activities, but also coordinate the ideas and actions among the participants. In other words, the models help to anticipate the outcome (Gal'perin 1969; 1979 in Van Oers, 2006), and to distribute meanings in a community.

Although there are many different definitions of models, the definition by Van Oers (1988) is used in this article. Van Oers stated that: "... a model can be described as any material, materialised (for example a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's actions ..." (p.127). Models function, in education as well as in science, as tools in a problem solving activity and are important in both individual and social cognitive processes (Van Oers, 1988, 1998). The key issue here is that models contain assumptions about reality and about the relationships between the model and the represented reality. It is not necessary to assume that models exactly copy reality. Rather, functional models only assume that the outcomes of (possibly mental) actions on the model correlate in an actual way with the outcomes in reality, if the same actions were performed in reality. For example, a drawing of a bike on a scale of one to ten assumes that relations and ratios in reality are maintained as scaled in the drawing. The models in various problem solving activities, in our case the process of designing and constructing a tricycle, differ in the number and content of the theoretical assumptions. Students need to know the assumptions in order to understand or create a model. This is how models can function as tools for knowledge (re)construction. The kind of models and modelling required in a setting contributes to the knowledge-richness of a learning environment.

Since the way students learn to model while they work and learn in a workshop at school will be studied, it is necessary to know what kinds of knowledge the workshop requires. In the learning processes of students, changes in the sort of knowledge the students have to acquire and use are examined. Guile & Young (2003) distinguished between different kinds of knowledge: tacit vis-à-vis situated; situated vis-à-vis codified; and codified vis-à-vis disciplinary. The authors make these distinctions because learning in workplaces is not only a process of participation, "but it also involves the acquisition of knowledge which may not be available in the 'communities of practice' in which [students] find themselves" (p.66). Hence, learning environments (in and outside school) which aim to teach more than just skills should be knowledge-rich.

First, Guile & Young pointed out the distinction between knowledge that can

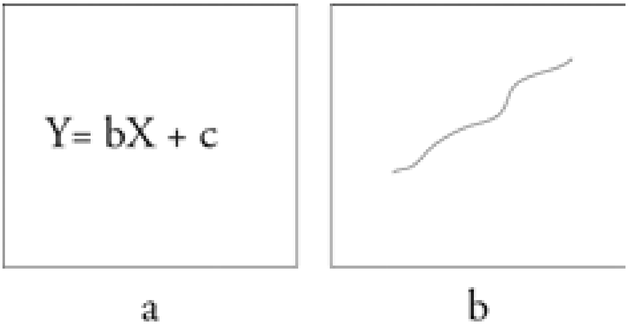

Figure 3.1 Canonical and situational model

or cannot be codified: "Whereas situated knowledge is that knowledge which is embedded in specific contexts but *can* be made explicit or codified, tacit knowledge refers to the knowledge associated with activities that *cannot* be codified" (p.68, italics added). Second, they explained the distinction between situated and codified knowledge: "This distinction recognises the difference between knowledge which is embedded in specific contexts and can be acquired by participation in those contexts and knowledge that is codified in bodies of rules that apply in a range of contexts" (p.69). Third, there are the distinctions between corporate, disciplinary and pedagogic knowledge, of which only the latter two are relevant to this study. The differences between these types of knowledge depend on the purpose of the codification. "Disciplinary knowledge is the form of codification traditionally associated with research and the production of new knowledge. Pedagogic knowledge is knowledge codified for instructional purposes – the paradigm for the school subject" (p.69), such as the academic discipline and school subject mathematics.

Different types of models can also be distinguished. A rough distinction can be made between *canonical models*, which represent a structured body of knowledge in symbolic form, and *situated models*, which represent personal or setting-bound images of a situation. In the picture below, (a) represents a canonical (i.e., in Guile and Young's terminology 'disciplinary') model of a straight line, while (b) represents a situational model. Characteristic of situational models is that they are mainly evaluated on their functionality in the situation given, or the problem at hand (van Oers, 1988). Thus, to create a knowledge-rich environment for modelling, codified or disciplinary models should be brought to bear in the community of practice in which teacher and students work together.

From the distinctions on the next page, it can now be determined whether a learning environment can be considered knowledge-rich or not. *An environment is considered knowledge-rich when it has the potential for students to acquire knowledge that is codified or disciplinary. In other words, knowledge-richness depends on the possibility of an environment that may bring students from situated and tacit knowledge and models, to codified and disciplinary knowledge and models.* In the case of technical education, that means for example that students do not use Pythagoras' rule for calculating the length of a piece of steel only once, but that they also understand it as a mathematical model that applies to a range of situations; that it is a tool in the discipline of mathematics which has practical and theoretical use.

Having distinguished between different types of models, and their relation with types of knowledge, the way in which learning and teaching in knowledge-rich environments occurs needs to be considered. What processes occur when a teacher helps students to develop adequate models in knowledge-rich settings? How does a teacher stimulate the students to design situated models and then lead them further to the appropriate codified and disciplinary knowledge and models? In the case study reported in this paper, a descriptive account of the teaching-learning processes in knowledge-rich environments in VMBO is provided.

As tools for orientation in complex activities, models in a knowledge-rich workplace should give direction to authentic activities towards more general or abstract knowledge. However, the models should not be limited to only one situation.

Van Dijk claimed that if the students are more actively involved, there is a better chance of acquiring the skill of modelling (Terwel et al, 2009). However, the question remains how to guide the students in their active involvement in the workplace. From the framework explained above, it can be concluded that if an assignment creates the need and opportunity for recontextualisation of students' knowledge and, at the same time, models are designed by the students under guidance of the teacher, the workshop at school becomes a knowledge-rich learning environment. By creating such a learning environment, a foundation can be laid for the acquisition of new knowledge, skills, and (situational, codified and disciplinary) models.

In this learning environment, the guidance of the teacher is crucial. The present case study explores the processes that develop as a result of this guidance. Does this guidance bridge the gap between problems students already can solve without help, and problems for which the students still need the help of the teacher (the expert)? This is what Lave and Wenger (2005) and Daniels (2005) called the 'scaffolding' interpretation of the zone of proximal development (ZPD). Although many different interpretations and descriptions are available, a core element is that scaffolding is an interaction process and thus dynamic (Renninger, Ray, Luft, & Newton, 2005; Van Geert & Steenbeek, 2005). As Stone (1993) pointed out, in many school-based applications of the scaffolding notion, something is seriously missing. Many examples of scaffolding lack the possibility for the students to see where the scaffolding process is bringing them. In other words, students cannot see the relevance of the guidance in respect to reaching their immediate goals. This opportunity to give meaning to the scaffolding process on the basis of a final, long term goal is called *prolepsis*. The lack of prolepsis is, according to Stone, a serious drawback of scaffolding in meaningful educational processes. Due to their nature, knowledge-rich learning environments optimally enable students to see the relevance of scaffolding for their work and to accomplish this prolepsis. The distant goal of their activity is clear and students can meaningfully relate to every step, and to the teacher's comments to this final goal. Adaptation of the appropriate scaffolding strategy is the key goal of a teacher. In addition to the construction of situational models (construction plans) for the construction of the product (a tricycle), the objectives of the learning processes which are embedded in knowledge-rich workplace simulations are the (re)construction and appropriation of knowledge from the domains of mathematics and natural sciences. In this study, the way in which the goal of the teacher and the objectives of the learning process are addressed in the classroom and workshop setting, will be analysed.

Method

The research project is *design based (*Shavelson, Phillips, Towne, & Feuer, 2003; The Design Based Research Collective, 2003), which means in our case that the first draft of the curriculum project was designed on the basis of available theory and in cooperation with experienced teachers. This project is studied in action in the first phase. In the second and third phase, it will be redesigned and used in an experiment with a control group. In this article, the first implementation of the designed curriculum project in a case study design is reported.

Curriculum project

During a period of twelve weeks, students (aged 14-16 years) had to choose what to design and construct: in subgroups of three or four for a 'real' client: a tandem tricycle or a bicycle game. The clients were a primary school principal and the owner of a party centre who were willing to buy the final products. Working for those clients provided a basis for the students' prolepsis during the design process, as in order to satisfy the clients, the students had a real interest in the quality of their final products. Initially, the assignment for the students was formulated in just a few sentences:

Please design and build:

a) one tandem tricycle made from two tricycles for children who are four to five years old, so that the children have to cooperate;

b) an indoor bicycle game, with two bikes on rollers which race each other, and includes a display of who is winning.

Students had to choose which of the two assignments they wanted to work on. Each group took a different assignment. In discussions with the clients, students were able to obtain a better picture of the assignment and the requirements of the end product.

For the teachers, the researchers described the assignment in more detail. In order to help them guide the students, two important issues were addressed in the description of the assignment. First, vocational teachers and mathematics and science teachers had to be able to guide the students in the application of the concepts and principles of science and mathematics. Second, teachers had to be able to guide the process of designing and building the product. Hence, problems that might occur during the construction process were explored in advance with the teachers. The researchers gave hints on how to resolve these problems and how to guide the students in exploring a solution with the help of scaffolds. These hints consisted of clues on the direction in which problems could be explored using mathematical and scientific modelling, and how this could be brought about by scaffolding. For example, in the meetings with the teachers the concept of “transmission” was considered to be a potentially difficult issue for students in designing the tricycle. Therefore, the team of teachers and the researcher explored several possible solutions and subject matter knowledge and models relevant to transmission, such as force, speed, vectors, and so on. In addition, which of the national educational goals could be reached by the students working on this project was made explicit.

With the help of the teachers, this curriculum project was constructed on the basis of several design and construction tasks for students in Dutch preparatory vocational education. A case study methodology was used to study the curriculum project (Yin, 2006). The objective of this case study was to determine if and how the concept of guided co-construction of subject matter knowledge and models was visible in the practical application of the curriculum project in action, and whether the learning environment actually became knowledge-rich. Consequently, the learning processes of the students and the learning environment were the main foci, and the research questions were: which educational processes occur in a simulated workplace using the concept of a *knowledge-rich* workplace? The criteria for determining if it was a knowledge-rich workplace were: the meaningfulness of the problems for the students, the development of situated knowledge towards codified and disciplinary knowledge and the (re) construction of appropriate situated, codified and disciplinary models. Following from the theoretical framework outlined in this paper, the interaction between teacher and students, among students, and between students and *tools* (i.e., models in this research), are the crucial moments for establishing if the designed project met with our criteria.

Research situation and sampling

For this first phase of the project, one school in the middle of the Netherlands was selected that had been working with assignments like the ones described above. With a team of teachers, the project was implemented in a workshop which was a simulation of a genuine working place. The workshop was situated in the school. In the workshop students worked with big machines and genuine workplace equipment such as welding tools and lathes. Together with the team of teachers we decided to separate out the design part of the "achievement"[7] from the construction part. In that way, students first received an assignment to design (on paper) a tricycle or a bicycle race game. Second, the team with the best design, chosen by a teacher jury, was allowed to build the product. The designing took place during a series of four mathematics lessons in the open learning centre next to the workshop. Students were able to use computers to search for information and to ask the mathematics teacher for help. After that, the construction of the products was done during the vocational lessons in the workshop under the guidance of the vocational teacher.

After the design phase, the students worked on the assignment every day for at least one hour in the workshop. In this workshop, computers were available and it was near the "open learning centre" where their mathematics and physics teachers taught other classes. It was in this space where they also had meetings with their tutor to discuss their progress once a week. The total duration of the project for the school was 12 weeks.

For this case study we followed two teams of students that were allowed to build their design. Six boys in two teams of three worked separately on their assignment. Team A was formed by one student (Ryan) working at the lowest level (basic level) of the VMBO and two (Sander and Alim) working at the second level of the VMBO (staff level)[8]. Team B consisted of Joost and Mohammed (both basic

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[7] The school's term for assignments

[8] Dutch preparatory vocational education has four levels/tracks: basic, staff, theoretical and mixed staff/theoretical. Students are graded according to their level. Students in our study worked in heterogeneous groups of basic and staff level.

level) and Raoul (staff level). Our unit of analysis were the subgroups and their teacher and their ways of participation in the classroom practice.

Data collection and procedures

Because of the focus on learning processes and the exploratory character of the study, we wanted to establish *thick descriptions* (Geertz, 1973; Goldman, 2007) or "closely observed descriptions" (Barone & Eisner, 2006, p. 97). We wanted to study changes in the participation of the students in their work and in group interaction over time in order to find evidence for learning (Erickson, 2006). For that reason three video cameras were used during observation in the classroom. One camera captured the overall picture of the classroom, one camera zoomed in on the activities and dialogues and one captured the interactions at the teacher's desk.

Most of the data we gathered came from observing two practice lessons a week during seven weeks with the three video cameras (thus a total of 14 lessons of 45 minutes). In those lessons we were able to follow both groups. Next, exemplary episodes of the lesson from a week earlier were shown to participants in a semi-structured video-supported interview to obtain their interpretation of what happened during that lesson (Clarke, 2002; see also Erickson, 2006). Episodes were selected if they contained interactions that occurred more than once in a lesson, or were ambiguous. These interviews were re-recorded and stored together with the classroom footage. By means of this first *member checking (*Stake, 1995), we were able to interpret the video observations together with the interpretation of the participants themselves. The procedure for the processing and analyses of the data resembles the whole-to-part approach described by Erickson (2006). Starting from the entire video data set, smaller pieces of video were then examined in more detail in order to find patterns in the data. For this inductive approach we used the Noldus Observer XT ("The Observer XT," 2009).

Pattern Analyses

The video data was subjected to multiple viewings to explore the footage for patterns. We used this method, known as pattern analysis (Erickson, 2004; Terwel, 2005), to allow the observers watching the videos to detect patterns in the data. These patterns are called *a posteriori* patterns. A pattern is a formal description of a repeating structure in interviews and in interactions. Patterns can be mentioned by the participants in interviews or can be noticed by the researcher during observation. Analysis was performed on the video data and the materials that the students created in their projects (such as drafts, designs, drawings and calculations) exploring only the a posteriori patterns.

First, two observers commented on all the video material using the comment function in the Noldus Software. Next, the video was viewed again, now coding the activities that seemed to enrich the learning. If necessary, comments were adjusted or added. An activity (i.e., an event in Noldus[9]), was coded as *enrichment* when it produced new information or knowledge on the basis of problem solving with the help of theory or general rules. In other words, *enrichment* occurred when tacit knowledge became explicit, or situated knowledge was transformed into codified knowledge. For example, calculating the length of a piece of steel with the help of Pythagoras' rule was coded as enrichment, whereas practicing welding was not. One hundred and eighty eight out of a total of 237 events were coded as enrichment. The observers agreed on 89 percent of the enrichment codes (Kappa = .72). Finally, all comments and codes of the two observers were brought together in order to formulate the patterns. For triangulation we explained those patterns to the team of teachers in a second member check session. They recognised all the patterns and agreed that the patterns were typical for their teaching practice.

Results: Three Patterns

The following section contains the description of three patterns which we found by analyzing the video data as explained above. Every description of a pattern uses the following structure: a title, an introduction to describe the pattern formally in general terms, episodes from the data as an illustration, and finally a conclusion with a reflection on the pattern.

In order to maintain coherence in the description of the results, the tandem tricycle assignment will be used to illustrate the patterns. The bicycle race game assignment will only be used if a contrast with the other assignment is needed.

Patern 1. "Let your mind work" outside the workplace, because time is scarce.

1.1 *Introduction*

In one of the first weeks of the curriculum project, Mr Williams, the technology teacher, was heard saying: "Let your mind work," three times in one lesson. It seemed to be an encouragement for the students to think. However, the students were given a task they had to perform at home, or in the mathematics classes.

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[9] In Noldus Observer XT an event is coded; a series of events is an episode.

Hence, some deeper thinking in the practice workshop can occur, but when students did not come up with solutions or answers fast enough, they had to find them elsewhere. Moreover, we can see that the teacher made an effort in teaching the students more than just the situated knowledge needed for the solution of a particular problem. In the beginning of the construction process, the teacher often referred to mathematics or he explained rules and possibilities in general. However, as the actual construction process proceeded and the teacher and students had less time, and the more situated and tacit the knowledge remained for the students, the less the teacher explained and tended to ‘give away’ or provide the solution to the students. This means that the students received increasingly tailored solutions and ‘tips & tricks’. In the workplace, time is scarce, so deeper thinking that takes more time has to be done outside the workplace, or, later on in the process, solutions are simply *provided* by the teacher.

1.2 *Episodes*

The students and teacher are gathered around a table with the drawings on it. Mr Williams, the teacher, discusses with the three students at the start of lesson two in the workshop how their drawing should be developed further into a construction drawing. He asks the students to explain what solutions they have for several construction issues. The dialogue is about the transmission of the tricycle (Excerpt 1.1).

Excerpt 1.1

Mr Williams: (technology teacher)	Ok, let’s see. I found out that a [front] cogwheel cannot be smaller than 30-32 teeth. Yeah? A separate cogwheel which one can normally attach to the back axis of a bike only seems be available with less than 20 teeth. So we have a ratio of one and a half (...) If we measure the distance the bike rides in one pedal turn, we can calculate (...) how much the other has to pedal. Agreed? Then we have to know the measurements of these tires [draws them] (...) Do you think you can calculate this, with help of another teacher?
Ryan:	We have to do that with Mr. Quinten’s help (maths teacher).
Sander:	What do you need to calculate this?
Ryan:	A calculator.
Mr Williams:	If this wheel turns once, how much does the child need to pedal? That’s what I want to know.

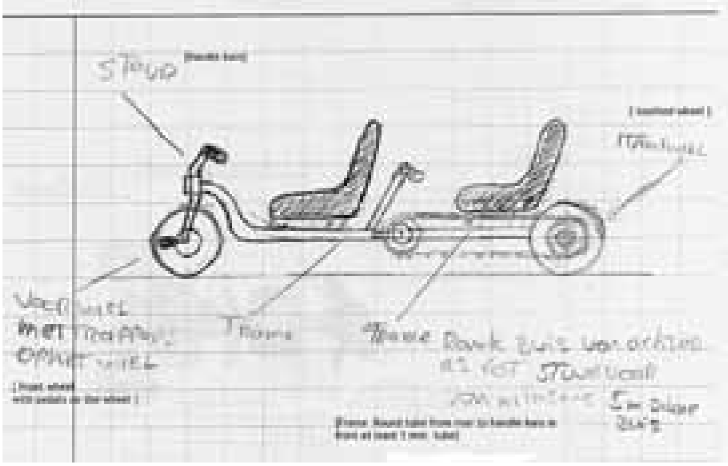

Figure 3.2 First draft of design of tandem tricycle drawn by students

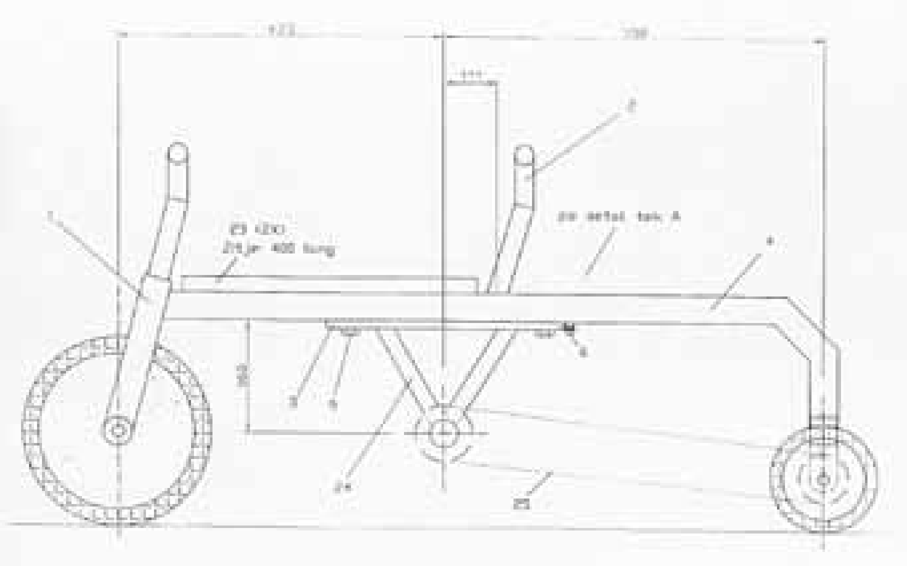

Figure 3.3 Technical drawing of students' design drawn by the teacher.

[*The teacher sends the students to the other teacher in the classroom next door.*]

In a conversation at the start of the lesson, the teacher checks if the students eventually found a solution to the problem. We can hear that some homework has been given.

Excerpt 1.2

Mr Williams: O.K. We can figure that out. Now, what did you find out about the ratio of the wheels? Did you go to the maths teacher?

In the classroom with the computers, the teacher gives Sander a design job to do at home.

Excerpt 1.3

Mr Williams: O.K. Ryan, you already did some design work, so you help Sander with designing the part on the axis that holds the toothed wheel. Then he can draw it at home and you can make it.

Later on in the process, in week five, the teacher finds a problem concerning the position of the crank. The teacher, in his role as a member of the design team, has to look again at the technical drawing (Figure 3.3) he made :

Excerpt 1.4

Mr Williams: Something is wrong here, because if the first handlebar is here and the other is here, then the second [child in the back of the bike] comes with his knees under the backend of the other [the first child on the bike] (...) O.K. I'll have to look at my drawing. Sander, you can saw the tube over here and here, but don't drill the holes. You can set the marks like this [*Shows it to Sander*]

In the final week, when Mr Williams is busy with many students, Sander asks him a question about the thickness of the steel. Mr Williams responds briefly and instructs Sander on how to resolve the issue of the steel. Sander's next question is about holes in the material:

Excerpt 1.5

Sander: Why do there have to be holes in the tube?

Mr Williams: Because if water runs in, it has to come out.

In one of the first interviews with the teacher, he confirmed that one of his jobs is to make sure that a quality product will get finished in the end, and therefore he provides the technical drawings:

Excerpt 1.6

Mr Williams: I think it is my job to get the project started well. I have tried it before, waiting until the students came up with their plans. But before you know, a week has past and then the plan of the project ends up in a folder or so.
(...)
If I didn't do anything, in the end a pedal will be welded somewhere randomly, a chain spanner forgotten and those kinds of things. There will be a product in the end, but I would not want to have it sent out to the client.
(...)
Let alone that they [the students] have to make a construction drawing, they are simply not up for it. The drawings and sketches they make, do not resemble a technical drawing. It think that it is my job to make a drawing they can work with.

1.3 *Conclusion*

The workplace is the place where the product has to be built. Therefore, the teacher is mainly concerned with getting things done and with the quality of the products. Although the teacher (Mr. Williams) sometimes tries to elaborate further on general issues, and tries to give students time to think about and understand mathematical issues (e.g. the concept of ratio), more often the students are referred to the teachers of the relevant subject, who in turn provide a solution (see excerpt 1.1. and 1.2). In the workplace, design tasks during the construction phase are homework (see excerpt 1.3). This may reflect what happens when the school becomes an authentic workplace: the client and product are the main concern of teacher and students. Consequently, learning or applying theoretical knowledge in order to advance the use of disciplinary models, has to be done somewhere else.

In and shortly after the design phase, there are opportunities for students to recontextualise situated knowledge about design and construction by students, to codified or even disciplinary knowledge (Guile & Young, 2003). That is, from a separate design problem and its solutions, the students are guided to apply more general rules and subject matter content. The dialogue between the students and the teachers can guide the students to reinvention of knowledge that is suitable for their problem; though this knowledge is generative in a sense that it becomes clear for the students that it can be used as a rule or a problem solving strategy. Later on the possibilities to recontextualise become scarce. The team and the teacher are working towards a deadline, and there is no time for elaboration. The tips and tricks students receive in this phase have the form of situated knowledge.

Patern 2. Problem solving starts with modelling, but solutions are often provided.

2.1 *Introduction*

As we focus on the students' problem solving, it appears that two different activities occur. First, students design situational models themselves when they are drawing the design or are planning their client interview. Second, canonical models, like models for technical drawing or mathematical rules, are provided by the teacher. As a result, no reinvention of these models occurs. The guidance teachers give on the canonical tools is one of providing students with answers or instructing students how the models should be used, whereas the guidance on the drafts and drawings of the students themselves helps students to transform drawings into the construction of a working model. In the case of Ryan, Sander and Alim their design is constructed by themselves, and the concept and use of ratio is simply provided by the teacher

2.2 *Episodes*

When Ryan, Sander and Amil are at the desk of the mathematics teacher to find out the ratio of the toothed wheels for the tricycle, the teacher helps them to solve the problem:

Excerpt 2.1

Mr Quinten:
(maths teacher) We can make this easier. We can just take the ratio of those wheels. If we know that ratio, we know the ratio of the transmission as well.

In the final interview with Sander and Ryan, Sander reacts first on how they solved the problem with the help of the mathematics teacher as described in Excerpt 2.1.

Excerpt 2.2

Sander: We had to know how big the toothed wheel had to be. Then we asked the maths teacher to calculate it for us. Euh, with Mr. Quinten's help we calculated it.

The three students need to know the length of steel they need. Mr Williams explains that they should use Pythagoras' theorem: (Excerpt 2.3)

Excerpt 2.3

Mr Williams: When you have an equation with only one missing variable, you can calculate that variable. Can you do that?

[*Students try, randomly, some figures*]

Ron: Oh, euh, a + b = c

Mr Williams: No, that's not what it said; c square = a square + b square.

[Finally one of the students comes with the solution to take the square root]

In an interview, the teacher reacts on the question 'who designs what?':

Excerpt 2.4

Mr Williams: In this phase, I'll take the lead. I have to make sure the ready made [*technical*] drawings get finished. We first have to determine how the product will look like and which parts are needed. That's what we'll focus on in this phase, because when we don't know that, I can't make the drawings.

2.3 *Conclusion*

Although we have seen that the likelihood that teachers provide models to students may be related to the time available (see Pattern 1), There appears to be also a difference in terms of sorts of knowledge. As students can model and draw their own design themselves, canonical models as tools (i.e., planning: the technical drawing in this example) or artifacts (i.e. the equation with one missing variable, or the theorem of Pythagoras) are simply provided. This provision of canonical models may be because the teacher reasons that providing models is more effective than having the students generate the models themselves (Rosenshine & Chapman, 1996).

Patern 3. A workplace simulation is stimulating

3.1 *Introduction*

Once the students realize that what they are designing and engineering can be constructed, they take more responsibility for their design, ideas and plans. Hence, they see it as a challenge and they develop 'ownership' of their design, whereas the teacher acts as a co-designer. As a result of this ownership, the problems they encounter in the realisation process are meaningful and authentic. The solutions become *their* solutions that they are proud of.

3.2 *Episodes*

Ryan, Sander and Alim are at the primary school for which they are making the tricycle. They are sitting in the office of the school principal, all looking very serious with pens poised to write down the answers to their questions (excerpt 3.1):

Excerpt 3.1

Sander: So, We'll make two bikes from one. We'll make the tube in one piece ourselves, otherwise it will have a weak point. (...) Is there any colour in particular you would like for the bike? (...)
Ryan: I think we can deliver the bike to the school in January.

When the group presents their product to an audience of students and teachers, they cannot stop talking about the solutions they have found. Their presentation takes more than 20 minutes, whereas presentations generally take about ten minutes.

In one of the first weeks, Ryan is enthusiastic about the assignment: "Hey, Mr Williams, we will really get it finished, don't you think?". In this lesson, Ryan and Sander really defend their design:

Excerpt 3.2

Ryan: So we thought of doing it like this. (…)
Mr Williams: But then you'll have the problem that the tricycle will not turn easily...
Ryan intervenes: Then we need to have one free wheel
Mr Williams: Exactly!

In an interview Mr. Williams reflects on why and how the ('real') assignments work:

Excerpt 3.3

Mr Williams:	Products that roll, turn or ride are always interesting [*for students*]. A stranger as a customer can be much more important than I think It is a exiting target group [*the six year olds for the tandem tricycle*]. It is very clear how, later on, the product will be used [*by the client*].

In a final interview with Ryan and Sander, they agree that they designed most of the tricycle themselves:

Excerpt 3.4

Ryan:	So, in this project we designed and made a lot of things ourselves. ... Also developed things.... We thought it was a good project. Yesterday, on the last day we had, we finished it.
Sander:	We still have to paint it to make it look better, although that [*painting*] isn't normally compulsory.

3.3 *Conclusion*

In this study, the embedding of student learning in a simulated workplace with real clients created optimal conditions for prolepsis and meaningful learning. Moreover, the tandem tricycle was finished, to the excitement of the team of students. Therefore, it can be concluded that the designing part of the assignment was crucial for the students: it motivated them and triggered the need for the acquisition of new knowledge and skills. They even seemed not to think it was possible to be able to complete the assignment successfully. The assignment may have been in their Zone of Proximal Development.

The three patterns described above provide evidence that the assignment designed for this study has the potential to be knowledge-rich. However, the guidance of the teacher seemed to be based on simply providing information and models to the students, rather than guiding them into recontextualisation. Contrary to expectations, the teacher did not often lead the students to more general knowledge or models. If a problem called for disciplinary or codified knowledge, the students were referred to other teachers or were expected to find solutions as homework. Most models or knowledge therefore remained situated. Somehow, the teacher's guidance in the classroom stopped at the situated and practical issues, which may have been caused by the time limit of the assignment. Situated knowledge was at stake when for example typical problems in students' design, like where to attach the crankshaft to the frame of the bicycle, had to be solved. Codified knowledge was required when students learned how to find the right configuration of a welding machine. An example of disciplinary knowledge was found when the mathematics teacher explains how to solve the problem of transmission by using the ratio concept.

The socio-cultural theory takes the concept of the Zone of Proximal Development as the main guide for promoting development (Daniels, 2005; Lave & Wenger, 2005). The process of guidance that can take place within the ZPD is optimally meaningful when prolepsis is possible for the students (Stone, 1993). It seems that although the assignment itself was one that can guide students within their ZPD, the teacher took over when problems called for codified or disciplinary models the students did not yet master. The teacher used the original design of the students, however, he did not have them design or reconstruct models needed for further processing the design into a product. The only model students really designed themselves was the first draft of their ideas. Students' own design stopped being a communication and orientation tool after the first draft. More codified and disciplinary knowledge and modelling may be acquired by the students when the teacher uses the students' need for solutions to problems and has the students generate and reconstruct the appropriate models and knowledge themselves. The students' models then become the tools for orientation and communication, and at the same time the need for codified and disciplinary knowledge will be in their ZPD. In other words: the teachers should be adapting to the ZPD of students, and leading them to reconstruct codified and disciplinary knowledge and models evoked by situated and practical problems emerging from working on the authentic assignment.

Conclusion & discussion

In this case study, an educational curriculum project for students was studied in preparatory senior secondary education (VMBO). This research was aimed at exploring the potentials of the designed project and constructing a framework instrumental for the follow-up research.

Research questions of this article were: which educational processes occur in a simulated workplace using the concept of a *knowledge-rich* workplace, and what is the role of models and modelling?

Our analyses resulted in a description of three patterns. In sum, it appeared that the process of designing a new product for real clients created moments and opportunities for students to use and learn models and offered the possibility of prolepsis that helped to organizing the scaffolding process in a meaningful way. This meant that the learning environment became knowledge-rich, in that finishing the assignment required different types of knowledge and skills, and created opportunities for students to acquire situated, codified and disciplinary knowledge. However, the analyses showed that the knowledge tended to be provided by the teachers and was taken outside the workshop as homework or to other teachers. The ratio problem in the design of the tricycle was an example which illustrated both the potential of the assignment, and the tendency that while more general, codified and disciplinary models was provided by (other) teachers, the mathematics teacher simply provided the students with information on the way in which the problem could be solved. This tendency of providing canonical models was apparent when knowledge was codified or disciplinary, or when there was no time for elaboration due to the deadline of delivery. The only models the students really designed themselves, were the drafts of the first design, or situational models. Models with more theoretical notions were provided and the use of these models was not further elaborated on by the teachers: hence models in the learning? process were mostly situated. Furthermore, students became truly motivated and owners of the problems when the client was "real", which was apparent when they could not stop talking at their presentation in front of their peers, and expressed in an interview that they had designed most of the product themselves.

As mentioned above, a conclusion of the current study is that the assignment was knowledge-rich and was motivating for the students, as it aroused the need for further and more specific knowledge and skills. At the same time, codified and disciplinary models were mostly provided by the teacher and the students did not generate them themselves. Since there seemed to be many opportunities while working on the assignment to use and create models, the question is how to make the reinvention of canonical models as authentic as the situational solutions are. Or, in other words, how the learning potential of the assignment in the simulated workplace becomes realized (Nijhof & Nieuwenhuis, 2008). The learning environment might become knowledge-rich when the teacher guides the students in improving their modelling by bringing in his knowledge and the appropriate cultural tools in order to (co)construct qualitatively better models that are meaningful for more than the unique situation. In other words, helping the students to reinvent models usable as orientation and communication tools in a learning strategy may create a knowledge-rich learning environment.

For the next phase of the current research project, an experiment was set up using a new curriculum project designed according to the outcomes of the present study. The assignment will be adjusted for the students so that designing will be a continuing process until the end of the project. Rather than being a design competition, the complete assignment will be a 'prototype competition' in which all students have to design and construct a prototype. In this way, it is hoped that the assignment can be made authentic for more students. In addition, the design and construction of a prototype may also create more opportunities for reflection on the process of designing and building. As Lave & Wenger (2005) pointed out, reflection on the work processes starts the legitimate peripheral participation. Moreover, designing a prototype may make the reinvention of canonical models more meaningful, as students have to come up with a production plan that covers more possible problems than the ones they have previously encountered.

Furthermore, special attention will be paid to the way in which the teachers are trained in guiding the students. The teachers will be instructed to bring their knowledge and understanding into the team of students in a co-constructive way, in order to guide the students in the use of the codified and disciplinary models that are meaningful tools for strategies of general (mathematical and technical) problem solving. In addition, because time is an issue in the practice workshop, other moments outside of the vocational lessons will be created to guide the students in the modelling.

4.

Learning in the school workplace: knowledge acquisition and modelling in preparatory vocational secondary education*

Abstract

This paper addresses the composite question of whether it is better in vocational education to allow students to design their own models and guide them while doing so, or to provide them with ready made-models. To answer this question we set up a design experiment in which students were asked to work on real-life assignments, guided by teachers in the process of designing their products while learning the necessary concepts and skills as they went along. The use of models was required during the design stage. The students were asked to design and build a tandem tricycle during a ten-week period. The experimental sample comprised 2 schools and 65 students, aged 15 years. A pre-test-post-test control group design was used to determine the results. The two conditions differed in the way models were taught: in the experimental condition the models were co-operatively designed by the students under teacher guidance; in the control condition ready-made models were provided. It was hypothesised that the students in the experimental condition would outperform their counterparts in the control condition on knowledge and modelling. However, it was found that both groups scored equally well on the post-knowledge test in science and mathematics, while the experimental group gained more on modelling. Implications for teacher guidance and school climate are discussed.

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Introduction

To strengthen the relation between theory and practice, schools for preparatory vocational secondary education (vmbo)[10] in the Netherlands and elsewhere are reforming their curricula (Biermans, Nieuwen, Poell, Mulder, & Wesselink, 2004; Guile & Young, 2003; Mittendorff e.a., 2008; Boersma, ten Dam, Volman, & Wardekker, 2009).The reform is aimed at engaging the students in work-related school assignments. The general question arises whether such assignments in fact improve the relation between theory and practice, and what knowledge could be acquired by working on such authentic assignments; in other words, whether understanding is fostered and if so, to what extent. This general question prompts two processing questions: if improvement is found to be significant, how do concepts and models become tools in gaining understanding of the knowledge domain they relate to, and how do they aid the search for solutions to practical problems?

In the context of innovative vocational education environments, learning in simulated workplaces is supposed to motivate students and provide them with the concepts, skills and mindsets necessary for further education and subsequent employment (Mittendorff et al., 2008; Van der Sanden & Teurlings, 2003; Boersma et al., 2009). In environments of that type students work on authentic assignments, such as constructing wine racks or tricycles, or on repairing their teachers' cars. The environments in question are simulated workplaces and may be considered 'communities of practice' (Lave & Wenger, 2005; Van der Sanden, Terwel, & Vosniadou, 2000). In a previous case study we found that working on such assignments creates opportunities for acquiring an understanding of modelling as well as technical knowledge (Van Schaik, Van Oers & Terwel, 2010a). However, the character of the learning environment in which the assignment was implemented was focused solely on delivering a product, so that the acquired knowledge tended to remain tacit and situated. Obviously, for deeper understanding, students need to be involved in a 'knowledge rich' learning environment, in which teacher guidance is aimed at the acquisition of more general knowledge codified in the subjects of the curriculum. The purpose of this article is to determine whether guiding students' collaborative learning leads to better results than simply providing them with the required knowledge and tools. In the collaborative learning process students reconstruct models and acquire vo-

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[10] vmbo is the Dutch name for secondary education for students 12-16 in their preparation them for senior secondary vocational education. Sixty percent of all Dutch students aged 12-16 attend vmbo (Maes, 2004). In this article we will use 'vocational education' to refer to vmbo.

cational knowledge by means of an ongoing and reciprocal process. We refer to such teacher-guided processes as co-construction.

In our research we are interested in the construction of models and vocational knowledge in a rich learning environment. Research has shown that the strategy of guided co-construction may lead to a better understanding of mathematics and modelling than a strategy based on simply providing models (Doorman, 2005; Terwel, Van Oers, Van Dijk, & Van den Eeden, 2009; Van Dijk, Van Oers, & Terwel, 2003). Reinventing the models under teacher guidance helps students understand the function and value of modelling (Gravemeijer, 1997). In addition, diSessa found that students are capable of (re)inventing models, e.g., graphs and drawings (diSessa, 2002;2004). Others have found promising forms of problem-based learning and problem solving programmes in real-life contexts (Kolodner et al., 2003; Hill, 1998). However, it is not clear how this type of model reconstruction is supposed to work when students work on real-life assignments in vocational education.

In the case study referred to earlier we implemented an authentic assignment at one school for preparatory vocational education. It was found that the teacher's guidance tended to be based on simply providing the students with ready-made models. Although the assignment clearly included many opportunities to help students gain a better understanding of mathematical and scientific models, the school's workshop culture was based on the precept to 'get things finished.' Hence, the use of models appeared to be situated and tacit, while the relevant knowledge and the models used remained situation-bound. Neither the modelling process nor the relevant knowledge were explicitly reconstructed. Problem solutions in those situations were provided by the teacher, and no time was spent on further exploration of the mathematical and scientific concepts (Van Schaik, Van Oers & Terwel, 2010a).

In the present study we build on these previous findings and report on an intervention. The focus is on codified knowledge and the understanding that students acquire when working on design and construction projects. We expect that by designing a technical product with teacher help students will be stimulated to improve, first, their understanding of technical and scientific concepts and principles and, second, the rules and their interrelations as represented in models (see, for example, Kolodner et al., 2003). The models thus become tools in practical problem solving while, at the same time, providing a basis for connecting practical use to theoretical knowledge. In contrast to our first case study, teacher guidance is more collaborative. The main issue in this research is whether co-constructing teacher guidance has a positive effect on codified knowledge and modelling.

Theoretical background

Introducing students to certain sociocultural practices (e.g., workplace *as well as* mathematical practice) is best described as a process of legitimate peripheral participation (see Lave & Wenger, 1991). In such a context, learning may be seen as a process of qualitative change in activities, resulting in enhanced possibilities of sociocultural participation (Van Oers & Wardekker, 2000). Such enhancement also contributes to *enculturation* into a community of learners (Brown & Campione, 1994; Lemke, 2000; Rogoff, Matusov, & White, 1996). When learning takes place in a workplace setting, the agents involved (students and teacher) may be characterised as a *community of practice* (Lave & Wenger, 2005). In such communities the participants share basic assumptions regarding the community's rules and purposes. As learners they are actively involved in meaning-making activities, as well as in problem solving with the aid of tools and artefacts, and communicating with each other as well as with others outside the community.

Furthermore, sociocultural theory shows that in the accomplishment of activities new goals and needs may emerge which drive participants to construct or adopt new tools (See, for example, Kozulin et al., 2003; Saxe & Guberman, 1998). Hence, by participating in communities, students may be compelled to aim for new goals that encourage them to adopt appropriate new practice-related tools, including concepts, symbols and models (Gravemeijer, Lehrer, Van Oers, & Verschaffel, 2002). In guiding the participation process teachers help their students understand the use and meaning of the concepts, symbols and models as tools in a range of similar practices. At the same time, the teachers themselves are participants in the same community and co-construction process as the students. It is important to remember that the teacher is not just a guide in this process of meaning making, but also a genuine participant (Van Oers, 2001). For example, the teacher may help students create a construction plan by asking questions referring to both domain specific rules for such a drawing and to the relevant mathematical concepts. In other words, teachers participate in the teams not only as guides but also as experts.

Guile and Young (2003), however, argue that for knowledge acquisition in a 'community of practice' participation alone is not sufficient. Teachers should focus explicit on relating both situated knowledge and more general knowledge as codified in the subjects of the curriculum. In our intervention the programme was aimed precisely at that objective: moving from practical problems to modelling, and, eventually, to an understanding of the relevant domain-specific concepts.

Although there are many different definitions of models, in this article we follow Van Oers (1988), who states that: "... a model can be described as any material, materialised (for example a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's actions … ."(p.127). Models are structured representations of physical or ideal realities, functioning, in education as well as in science, as tools in problem solving activities. As such they are important in both individual and social cognitive processes (Van Oers, 1988).

From a sociocultural point of view models have two core functions: orientation and communication. These functions are not mutually exclusive. Orientation, according to Gal'perin, is an essential cultural action moment. From that point of view, a model is a cultivated tool for orientation towards actions to be performed (Van Oers, 2006). It gives direction to a person's activities. Orientation is a cognitive activity. It includes valuation, produces information, and functions as a basis for plans and predictions. As tools for communication, models foster the distribution of individual ideas and meaning across the community. When students work together, as in our case, on the construction of a tricycle drawings, plans and ideas are used to plan and predict the process, and to discuss the final design. The models give direction to not only to the actual design and the planning of the activities, but also to the coordination of ideas and actions among the participants. In other words, the models assist in anticipating the outcomes and meaning distribution in a community (Gal'perin 1969;1979 in Van Oers, 2006).

In vocational education students both design and construct real products. In the design process, as well as in the actual construction, problems arise and need to be solved. In the anticipation of possible problems and their solutions models may be used. For example, a model may allow the designer to calculate drawing angles in advance so that steel may be sawn correctly in a single process rather than by trial and error. Here the mathematical formula functions as an orientation tool.

Although drawings and models are important in design technology and serve both to communicate and generate ideas, MacDonald & Gustafson (2004) claim that in classrooms the emphasis is on their representational function. That is, models are not used as thinking tools. When drawing in classrooms is related to orientation and exploration of ideas, modelling may turn into an action-learning strategy, by which students gain deeper understanding of problems and their possible solutions.

By collaboratively reflecting on, and improving the production process participants learn to understand the, often tacit, rules and codes of the workplace and the knowledge that underlies such rules and codes. As prototypes, models could function as tools to aid students to think ahead and reflect on their own processes. As a result, students' understanding could grow.

The important role of the teacher, as guides to knowledge acquisition and understanding in practical environments, also includes introducing students to the practice of modelling with the aid of mathematical tools. The teacher's role is to identify what is 'mathematical' in workplace practice, as well as to recognise the students' emergent need for mathematical tools, and to relate such recognition to the practice of (mathematical) modelling (Van Oers, 2001). However, providing models is not sufficient to understand the use of models as tools; in addition, conditions should be created which focus "… on the hidden rules and assumptions in the tools." (Van Oers, 2001, p.81). Teacher guidance should therefore promote such understanding by helping students to co-construct the models.

The theoretical background sketched above leads to the following general hypothesis: *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 following three questions divide learning outcomes in terms of theoretical knowledge, test modelling and workshop modelling :

In a community of practice,

1. Do students in the experimental condition acquire more knowledge and a better understanding in 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?

Method

Research context & participants

This study may be regarded as a design experiment (Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004; The design based research collective, 2003; Shavelson, Phillips, Towne & Feuer, 2003). Based on case study findings (Van Schaik, Van Oers & Terwel, 2010a), we designed an educational programme for students in preparatory vocational education aimed at modelling. A pretest-posttest control group design was used. The effects of the intervention were determined after controlling for initial differences, e.g., student characteristics and pre-knowledge. Due to the naturalistic nature of the design experiment not all possible variables were controlled for. For example, content of subject matter classes, group composition, teacher experience and actual time spent on the assignment, as well as students' previous experience with these kinds of assignments could all affect the outcome. Consequently, in addition to test-scores, interviews and video observations were used to study the intervention process. As a characteristic design based research this study is also intended to further develop the concept of intervention. As such it may be regarded as a pilot study situated between the first case study and a larger experiment.

The participants in this study were a group of 15-year-old students (n=65) at two schools for preparatory vocational education. During the practice lessons students in both conditions worked in mixed groups of the two lowest learning tracks: basic and staff level.[11.] We assigned both schools to the condition that best fitted their everyday practice, as explained above. This means that we adjusted the training and guidelines of the programme in this intervention to the teaching practice of the schools, which we identified during a visit and from interviews with the teachers. The school in the experimental condition works with authentic assignments over the complete curriculum from first to fourth grade, including mathematics and science. Students at that school are used to initially solving problems themselves and are stimulated come up with their own models and solutions. Teachers guide them in the exploration process. Students finish their projects with an individual portfolio assessment by the teacher. The teacher's teaching methods in the experimental condition most resembled our assumptions on how to guide students to understand and use models in a co-constructive way.

The school in the control condition works with authentic assignments as well, but only in the practice lessons. Theoretical subjects (mathematics, science) are taught in the more traditional way of direct instruction. In addition, the practice teachers tend to *provide* the solutions to practical and theoretical problems. This means that when a problem is identified after identification by the teacher a solution is instantly provided. For example, when a student wishes to know how to determine the length of a piece of steel from a drawing, the teachers simply provides the formula. At the end of every assignment students are graded for their product and presentation. All the student has to do is work out the solution. In other words, the school's approach is consistent with the more traditional way of providing models.

Intervention

The intervention started with a session with the teachers in which the aim of the intervention was explained and discussed. The teachers were provided with an educational instrument that consisted of a lesson plan and examples of problems

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[11] In VMBO students are divided into four 'learning tracks.' They differ on the theoretical level of the subject matter. The four levels are labelled 'basic level' (lowest theoretical level), 'staff level' (second theoretical level), 'mixed level' (intermediate level) and 'theoretical level'(highest theoretical level).

that might occur during the students' design processes. Teachers were supposed to pay explicit attention to relating situated knowledge to more general knowledge; moving from practical problems to modelling by the use of mathematical and scientific concepts.

The differences between the conditions concerned the way modelling was introduced. In the control condition the models were to be ready-made and provided as solutions to the students' problems; in the experimental condition the students were to be stimulated to design or (re) discover the models themselves. We collaborated with the teachers at every school on adjusting the educational programme to the teachers' needs and practices. However, the core of the intervention was maintained: guided co-construction versus providing. At each school the daily organisation and routines were different. The differences consisted, in particular, in the ways in which theoretical subjects were integrated into the practical lessons and assignments. In addition, practical workshop lessons in vocational education were subject to continual change in that teams of teachers were often responsible for workshop guidance.

In making local adjustments we respected the agency of the participants and, as a result, programme changes when used by the participants as tools. An appropriate way to characterise our method would be to place it in the tradition of formative intervention (Engeström, 2007;2008). We also acknowledge the complexities involved in studying different school practices (Goodlad, Klein, & Tye, 1979). Details of the way the intervention developed are reported in de results section.

Intervention design was primarily based on experiences from an earlier case study (Van Schaik, Van Oers & Terwel, 2010a), which explored workplace learning in vocational education and the knowledge richness of the assignment. We found that designing and building a tandem tricycle may evoke the use of models and technical knowledge. Together with teachers and experts on modelling and mathematics the intervention was redesigned, taking into account the specific educational context. It was subsequently adjusted to the two conditions. For the experimental condition the intervention was flexible and open in order to help the teachers guide the students in more co-constructive ways. By contrast, the intervention was fixed for the control condition. This meant that in the corresponding lessons direct instruction was used and that the lesson contents were ready-made.

Assignment

Students were asked to design and construct a prototype of a tandem tricycle. Teachers assisted the students in solving problems of design or production that might occur. The students were stimulated to use or develop models to solve the

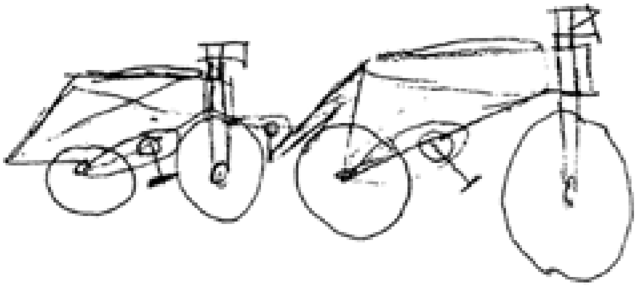


Figure 4.1 First drawing of tricycle

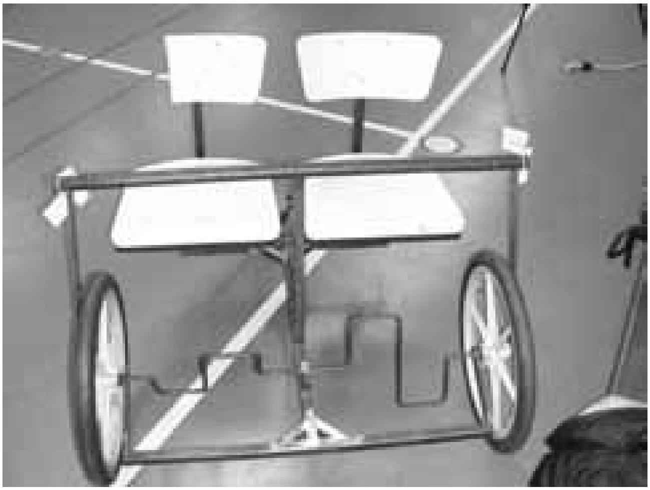
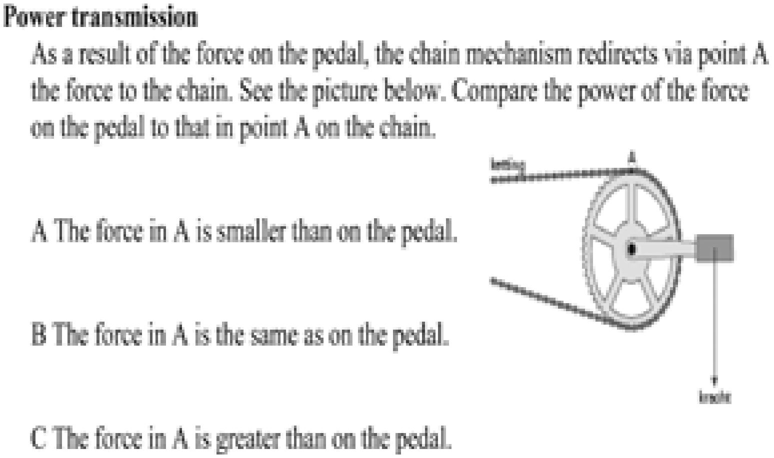


Figure 4.2 Picture of winner tricycle



Power transmission

As a result of the force on the pedal, the chain mechanism redirects via point A the force to the chain. See the picture below. Compare the power of the force on the pedal to that in point A on the chain.

A The force in A is smaller than on the pedal.

B The force in A is the same as on the pedal.

C The force in A is greater than on the pedal.

Figure 4.3 Sample test item on power transmission problems they were faced with while working on this 'real-life' assignment.

The student assignment was formulated as follows:

Design and build a prototype of a tandem tricycle for children aged 4-7 in such a way that the children have to cooperate in the process of cycling.

The assignment was placed in the context of a competition.

The tandem tricycle had to be designed and constructed in a ten-week period by the students. During that period they worked at least two hours a day in the workshop setting and in open classrooms where computers were available. In both spaces teachers were available for questions and guidance. The design process was reflected on and discussed during workshop hours and in lessons or sessions separate from the workshop and the construction process. During workshop practice mainly practical problems occurred. These were mostly solved on the spot or redirected to the separate lessons. During the separate lessons the students were guided by teachers in problem solving with the aid of models, while using their designs and applying their knowledge of science and mathematics. The students' involvement started with an introduction by the researchers, in which the aim of the assignment was explained: building a prototype to win a competition. The students subsequently started designing during the first week (see figure 4.1 for an example), moving on to construction during the weeks following. The competition ended with the selection of the two best prototypes for each school, followed by a finale during which a panel of judges decided on the winning prototype design (figure 4.2).

Instruments and procedure

To measure the students' pre-knowledge of mathematics and vocabulary, we administered several tests. The first were two pretests, one measuring vocational knowledge, the other measuring understanding of modelling. The knowledge test consisted of 17 items, derived from national exams, to test mathematical, scientific and technical knowledge. The maximum score was 37 points, with Cronbach's alpha as .78. Figure 4.3 represents a sample item from the knowledge test.

The modelling test consisted of a semi-structured item on how to construct a cart engine plus a visualisation and drawing task (see figure 4.4). The post-knowledge and post-modelling tests were almost identical to the pretests. (Crohnbach's alpha for the post-knowledge test was .82.)

The second test of understanding besides the modelling pre- and posttests involved an assessment of the students' final drawings of the products that had been designed and constructed by them (see figure 4.5). A team of four experts

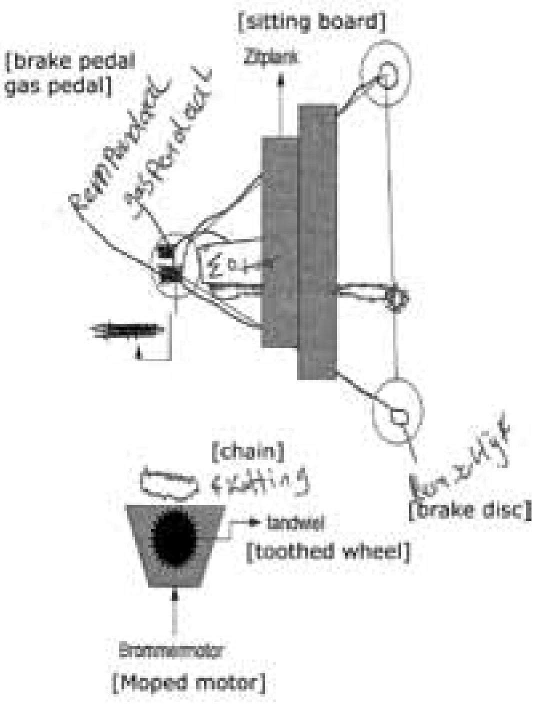


Figure 4.4 Sample test item on modelling

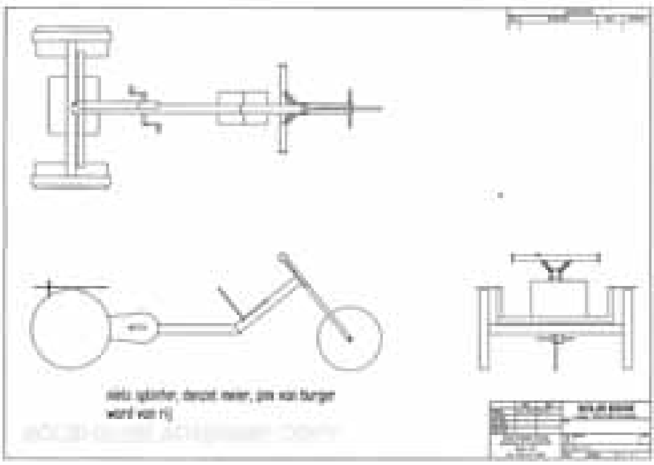


Figure 4.5 Final drawing of the product of a group in experimental condition

rated the drawing by each group according to four criteria on a four-point Likert scale. The criteria were derived from diSessa (2002), as applied by Van Dijk (2002), representing criteria for a qualitatively effective model: structure, clarity, accuracy and completeness. The experts, who were developers of 3-D modelling software, scored the models without knowing the conditions under which they were constructed. Inter-rater agreement were determined by Cohen's kappa (.89). The final tricycles were also rated by the same experts. However, since the inter-rater agreements proved unsatisfactory, we did not use them for our analyses.

Guided co-construction requires a repertoire of concepts and words (vocabulary) for mutual understanding. However, students differ in their ability to verbalise, elaborate and explain their ideas and solutions. Consequently, they may benefit differently from these complex collaborative learning processes. Students who elaborate and explain their ideas and representations learn more than students who do not. From this theoretical chain of reasoning it was expected that vocabulary would be one of the predictors of the learning effects in this kind of learning environment. A vocabulary test was therefore included as part of the measures to determine student characteristics at the start of the intervention, based on a national vocabulary test with a reported alpha of .89 (N=2200). The vocabulary test was administered by means of computers.

In order to follow the implementation of the programme participants, both teachers and students were interviewed during the intervention and afterwards. Lessons were observed using three cameras: two fixed cameras recorded the overall classroom activities, while a hand-held camera recorded the interactions between students and teachers close by.

Results

Table 4.1 shows that both conditions differ in age and pre- and posttest scores. However, further exploration on the differences by means of an ANOVA revealed that only differences in age were significant, $F(1,64)=49.29$, $p< .01$. In the control condition students are 13 months older (mean control group=199.6 months; mean experimental group= 186.2 months).

The regression analyses are divided into three categories of outcomes, according to the three separate research questions (and their three dependent variables). We will first consider the learning outcome on knowledge; we will then address modelling as measured by means of the tests; finally, we will examine the final product

Table 4.1 Descriptive statistics and pre- and postmeasures

	M	SD	Min	Max
Control group (n=15)				
Age (in months)	199.6	6.42	190	210
Vocabulary	64.73	13.66	40	84
Pre-knowledge	15.25	8.95	2	30
Pre-modelling	2.61	2.48	1	8
Post-knowledge	16.83	6.53	5	24
Post-modelling	2.31	2.39	1	8
Experimental group (n=50)				
Age (in months)	186.1	6.60	176	206
Vocabulary	64.96	12.45	41	101
Pre-knowledge	13.02	5.44	4	29
Pre-modelling	3.69	3.49	1	12
Post-knowledge	14.40	5.22	3	24
Post-modelling	4.69	3.28	1	12

Table 4.2 presents the correlations between the main variables. The relation between the variables is further explored by means of regression analyses.

Table 4.2. Correlations

	Age	Pre-knowledge	Pre-modelling	Post-knowledge	Post-modelling	Modelling product	Condition
Age (in months)		-.06	-.00	.05	-.19	-75**	-66**
Pre-knowledge			.23	.77**	.27	-.16	-.14
Pre-modelling				.20	.48**	-.15	.17
Post-knowledge					.23	.06	-.18
Post- modelling						.09	.32*
Modelling of the product							.64**

** correlation is significant at 0.01 level (two-tailed)

* correlation is significant at 0.05 level (two-tailed) models of the students as rated by modelling experts. As shown in table 4.2, we started with the main variables for each regression analysis. Only the statistically significant results are reported.

Knowledge as measured by the post-test in mathematics and science

As regards knowledge of mathematics and science, the outcomes of the regression analyses did not confirm our hypotheses. After controlling for initial differences no significant difference in outcomes remained. As evaluated against the initial differences on vocabulary and the pre-modelling test scores, the adjusted mean for the experimental condition was 14.67 and 14.03 for the control condition. The adjusted mean knowledge gains, evaluated against the same covariates, were 1.30 and 0.64 respectively.

Modelling as measured by the post-test in modelling

With regard to post-modelling measured by the post-test the outcomes of the regression analyses also failed to confirm our hypotheses. However, a trend in the expected direction was found. Evaluated against initial differences on vocabulary and the pre-modelling test scores, the adjusted mean for the experimental condition was 4.64 and 2.85 for the control condition. The adjusted mean knowledge gains, evaluated against the same covariates, were 1.30 and -0.64 respectively.

Modelling of the product

The final outcome variable, i.e. modelling of the product, consists of the final product model, as drawn by the students and rated by modelling experts. It should be noted that these drawings were group products, and that the group scores were assigned to individuals in their groups. Tables 4.3 and 4.4 present the outcomes of the regression analyses.

Model 2 in table 4.3 shows that 63 per cent of the variance can be explained by the predictors age and the interaction variable age*condition. The variables pre- and post-knowledge, pre-modelling and vocabulary were not significant. Younger students scored better on drawing the final model.

Looking at the coefficients, the interaction variable predicts the score negatively (table 4.4). This means that younger students benefit more from the experimental condition than older students. Although our final hypothesis, namely that students in the experimental condition produce better drawings, could not be confirmed; there was an interaction effect of age*condition. It turned out that

Table 4.3 Regression analysis for variables predicting the scores on the dependent variable modelling of the product (N=35[3]).

Model	R Square	Std Error of the estimate	R Square change	F Change	Sign. F Change
1	.55[1]	10.50	.55	33.83	.000
2	.63[2]	9.64	.08	7.22	.011

1 Predictors: (constant), age in months

2 Predictors: (constant), age in months, interaction age*condition.

3 Group scores

Table 4.4 Coefficients of regression of the predictors on the dependent variable modelling of the product. (unstandardised scores)

Model 2	Unstandardised coefficient		Standardised coefficient		
	B	Std. Error	B	t	Sign.
(Constant)	110.04	58.69		1.88	.070
Age in months	-.49	.30	-.32	-1.65	.109
Interaction age * condition	-15.15	5.64	-.51	-2.69	.011

younger students in the experimental condition performed better on their final drawings than their counterparts in the control group.

Enactment of the programme

Since this study is a part of ongoing process and constitutes the first step to a larger experiment, the enactment of the intervention is reported in the result section. In line with the notion of formative intervention (Engeström, 2008), it is important to know how the instruments with which the teachers were provided (i.e., the educational programme) were used and how they were adjusted by the teachers. Moreover, the analysis of the actual enactment might shed some light on the earlier quantitative results.

Below we present the actual method of programme enactment, that is, the development of the intervention when participants, teachers and students, were engaged applying it. In order to check the enactment with the intended programme, we used indexed observation data. The indexed observations were subsequently viewed and content-logged. We would like to reiterate here that the intervention was, as much as as possible, kept identical for both conditions with regard to student introductions (as carried out by the researchers), assignment content and rules, and suggested teacher content. The main differences discussed below concern the results of the intended differences effected by the researchers in the training sessions (i.e. providing models versus guided co-construction) in combination with teacher agency and, subsequently, the development of the intervention in each specific school context.

The main differences in enactment were time spent on the assignment and the way students finished the assignment, as concluded on the basis of the diary we kept as well as the actual school schedules. Regarding the time spent on the project, the experimental condition took fewer weeks than the control condition (three weeks in all). The project for students in the experimental condition appeared more condensed. The project in the experimental condition was fitted more strictly into the school semester. Although the school in the control condition took more time, this was not case for all students. After finishing the first semester students were regrouped and the two as yet unfinished tricycles were worked on by partly new groups. Moreover, according to the content log analyses for the practice classes, only a few students in the experimental condition worked on the tricycle during the practice lessons. Others continued working on other assignments. Apparently, the curriculum was more adaptive: students maintained their own speed and pace in their activities, whereas the other students in the control condition were to a much greater extent at the same point in their programmes and projects[12]. In addition, the students in the experimental condition finished the semester for which their assignment was planned with an assessment, whereas their counterparts ended theirs with a presentation for peers and teachers.

The observations showed that in the control condition models were present in the workplace until the project was finished, whereas in the experimental condition they tended to disappear after the actual construction began. Also, in the control condition there was no specific whole class instruction by the teachers on project-planning and drawing, as was the case in the experimental condition. From this we conclude that in the experimental condition the explicit attention to modelling was focused mainly on planning, which stopped when construction began. Excerpt 1 shows a transcription of two interactions during the corresponding specific 'planning lesson' in the experimental condition.

Excerpt 1: experimental condition

1.1. After a short introduction on planning, students work behind computers and the teacher comes by to check on one of the subgroups:

Teacher: You guys are drawing already?
Student: [inaudible]
Teacher: First, make a plan of action
A plan of action means,
'What do you want to create?'

1.1. Later he checks with another subgroup after complimenting them on their original idea:

Student: Yeah, but how do you construct the frame?
Teacher: Construct what?
Student: The frame.
Teacher: That depends on the expertise and knowledge amongst yourselves.

By contrast, in the control condition explicit attention was maintained on the models during the entire project. However, attention was focused on representing the models correctly in construction plans rather than on using models as tools.

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[12] This may appear logical since we were to have two conditions differing on those issues. However, during implementation the enacted programme is not always identical to the one on paper.

In the transcript below (excerpt 2) a discussion between the teacher and students in the control condition shows how the teacher asks the students about their ideas and shows them how to draw their designs.

Excerpt 2: control condition

On a table in the practice workshop, the teacher discusses the subgroup's design with the students. There are sheets of paper with several drawings on the table. The question concerns attachment of the back wheels to the frame.

Teacher: Let me draw a picture of the rear.
[Teacher draws while talking]
Here you've got one wheel. Here's the other. A fork will bridge it (which has a certain thickness, but I'll leave that out for the moment). And here is another fork. There's the tube with the chairs (…)
How do I get from this tube to these two connectors?
Student: Connecting those two to these two here
[while pointing to the appropriate places in the drawing]
Teacher: So you make a connection in between here and here
[continues drawing]
And then I take that one again
[Takes the other drawing]
That one is in here. And that one goes there.
[Points back and forth between the two drawings]

The discussion continues and turns to transmission.

In semi-structured interviews, teachers reflected on their student guidance. From the interviews it was clear that the guiding process in both conditions was in line with what we had expected: in the control condition students were provided with the models, whereas in the experimental conditions students were guided in their process of exploration. Moreover, the models in the experimental condition were intended to be used as tools for thinking and exploration, while serving as (part of) a construction plan in the control condition. The teachers in both conditions agreed on the difficulties the project presented to the students. To get from the idea of a design to a usable design was hard for them: "... students have a hard time imagining during the work preparation what it [the product] will look like in reality" (experimental condition teacher). Or: "... [I] don't ask them to do the drawing themselves [the technical design model], because they are unable to" (control condition teacher). As expected, the teachers differed in their responses to guidance. In the control condition the teacher made the technical drawings for the students: "... they learn by having it [technical drawing] provided." In the experimental condition the teacher wants to: "... expand the students 'thinking range,'" and, "guiding the students by showing and making them think [with models]. They learn through exploring."

Conclusions & discussion

This study explores learning in the school workshop. In an intervention, students were selected to cooperatively design and build a tandem tricycle prototype. In two conditions teachers assisted them in solving problems, varying from the very practical to the theoretical. In the control condition models were provided as ready-made problem-solving tools. In the experimental condition models were collaboratively designed and reinvented by the students themselves under the active, co-constructive guidance of the teacher.

The research hypothesis was as follows: *students who participate as model designers in a process of guided co-construction with an expert (teacher) in the company of peers show better learning outcomes than students who learn to work with ready-made models provided by the teacher.* The following three specific research questions were formulated to compare results for a control group and an experimental group of students:

In a community of practice,

1. Do students in the experimental condition acquire more knowledge and 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 product?

The answer to first question is negative. Analyses show no difference between the conditions regarding knowledge of mathematics and science. The anwer to the second question, regarding modelling, is tentatively affirmative, though only as a trend. Students under co-constructive guidance while working on authentic assignments have a better understanding of modelling. The outcomes concerning the third question are interesting. Although our hypothesis could not be confirmed, i.e. that students in the experimental condition produce better final product drawings, there was an interaction effect of age*condition showing that younger students in the experimental condition produced better scores on their final drawings than their counterparts in the control group. This effect might be related to the possibility that the older students had stayed down at some point during their school careers and thus were weaker students? With hindsight, this could mean that the experimental condition asked too much of those students.

The limitations of this study were its small scale and the complex environment. Sixty five students in two schools participated, and not all of them were able to do all the tests. It is clearly desirable that more schools and students should participate in future research. However, as already implied, preparatory vocational education is a complex research context. Students may switch from their majors, attend different classes for different subjects, or follow different trajectories and learning tracks, etc.. In addition, they have to deal with subject teachers as well as practice teachers, only some of whom are able to cross those domains. This made it impossible to implement a ready-made programme for each condition. As anticipated, the teachers' programme was subject to adjustments and changes prior to implementation. Consequently, the formative intervention approach (Engeström, 2008) turned out to be a good way to understand the implementation process. Moreover, it led to intervention enactment reports as a result. In contrast to Blokhuis & Nijhof (2008), we do not regard teacher adjustments and educational context dynamics as posthoc methodological problems. Since the study is part of a design-based research project, findings on how the intervention actually worked in practice constitute results to be used for follow-up research. For example, at the next research stage we must find ways of maintaining students' focus on their models for the entire project.

Comparing the two conditions of programme enactment with regard to teaching methods, two main differences were observed.

First, from interviews it became clear that the teacher in the experimental school was focused on " making the students think" with the aid of drawings. In other words, the students' drawings became the tools for student-teacher communication. By contrast, in the control condition, the teacher 'spoonfed' the students by by drawing the models for them. On the other side, however, the teachers in the control condition devoted more explicit attention to the use of models (as provided by the teachers) for the duration of the entire project.

Second, in the experimental condition the method of student assessment is shown to have been formative and intended to help students formulate new learning goals. By contrast, in the control condition the method of assessment was summative, aimed at grading the students on their product and presentation. Furthermore, the role of models differed across the conditions as regards the way they were used as orientation tools. In the control condition the ready-made models functioned mostly as explanatory devices or as construction plans, whereas in the experimental condition models were used to generate ideas and solutions. As MacDonald & Gustafson (2004) argue, this could mean that the creative use of drawings as open and multi-purpose tools may lead to a better understanding of those tools.

The outcomes of our study suggest that students in the experimental condition were better able to design models, both in the test, although not significantly, and in their own final product designs. The outcomes also show that knowledge acquisition was identical for both conditions. The teaching method in the experimental condition was more open, though less explicitly or continually focused on modelling. This leads us to the conclusion that the co-constructively guided teaching explicitly focused on modelling, and that, consequently, the use of models as tools may have a positive effect on domain-specific student learning outcomes and students' understanding of modelling.

The results from the present study show the findings to be partly in line with other research on modelling. Van Dijk (2002) as well as Keijzer and Terwel (2003) found that teaching modelling co-constructively leads to better results in primary education. Doorman (2005) proposed that the application of guided reinvention in teaching modelling helps secondary school students achieve a better understanding of graphing change. Others (Jurow, 2005; McArdle & Ackland, 2007; Van der Sanden & Teurlings, 2003) have argued that learning from practical experiences, project-based curricula, or authentic assignments improves transfer of knowledge. Guile and Young (2003) are more critical, arguing that participation in a 'community of practice' alone is not sufficient for knowledge acquisition, and that teachers should pay explicit attention to relating situated knowledge to more general knowledge. In the present intervention the programme was aimed at precisely that objective: moving from practical problems to mathematical and scientific modelling.

Further research will hopefully produce more qualitative examinations of the way models function as orientation and communication tools in the workshop, as well as how deeper understanding and knowledge acquisition depend on teacher guidance (with specific reference to providing versus co-construction). Put differently, "How those tools are enacted in particular circumstances and activities is crucial" (Billett, 2001, p. 447).

Other notable suggestions from teacher interviews included remarks such as the following, ”Students just don't come up with mathematics" and "[in the workshop] … there is hardly any relation between theory and practice." In light of such remarks, our next programme design will pay more explicit attention to theory *as derived from practical problems*.

The context of preparatory vocational education is rich and complex. Students learn while working on real-life assignments and as a result gain knowledge and improve their modelling. However, due to its complexity we will need to continue studying this rich environment and to focus in particular on *how* teachers and students use the models as orientation tools.

All in all, the experimental students gained in mathematical and scientific knowledge to the same extent as the controls. We may therefore conclude that 'haphazard' acquisition of such knowledge in the practical context of designing and constructing is able to compete with explicit, traditional instruction in mathematics and science. This conclusion may be seen as an advantage, especially for practically oriented students in vocational education. Finally, with regard to modelling, a trend was found to the effect that students in the experimental condition outperformed their counterparts in the control condition. This suggests that co-constructive teacher guidance may facilitate students' understanding of models as tools for communication and orientation.

5.

Tools for learning in simulated workplaces: results of an intervention in pre-vocational education*

Abstract

Are models to be provided or designed in a process of guided co-construction? The present study examines the way in which groups of students gained knowledge in mathematics and science by designing and using models while working on technical assignments i.c. a tandem tricycle. Four schools and 87 students were 8-10 weeks involved in a quasi-experimental design. After controlling for initial differences no differences in learning outcomes between the treatments could be found. The hypothesis had to be rejected. The schools with a tendency to better learning outcomes were schools with practice teachers who had a background in mathematics or science, a higher teacher-student ratio and students with higher scores on the pre-tests, than the other school.

* This chapter will be submitted as an article.

Introduction

In this article we report on a study in pre-vocational education (VMBO)[13], which examined the effects of an intervention aimed at enhancing students' codified knowledge in mathematics and science, as well as their understanding of modelling, while in the process of designing and constructing a tricycle.

In many educational settings knowledge is codified in subject matter textbooks and other curriculum tools, most of it derived from academic disciplines (Eraut, 2004). In vocational education, as well as in workplaces, codified knowledge is also available in bodies of rules (Guile & Young, 2003) and other specific tools, including, for example, machine manuals. Students in vocational education have to acquire this knowledge and at the same time become skilled in relation to their future professional practice. They are thus required to obtain competencies in order to be prepared for future demands, including codified knowledge as well as technical skills and attitudes (Cedefop, 2009; Commission of the European communities, 2008). However, relatively little research has been carried out into the type of learning environment in vocational education that is supposed to promote this kind of learning (Koopman, Teune, & Beijaard, in press).

The abbreviation VMBO denotes the system of preparatory vocational education at the secondary level in the Netherlands (Eurydice, 2008; Maes, 2004). Students between 12 and 16 years old follow a general curriculum with a vocational perspective. Work experience for students is organised both in school workplaces and extramural apprenticeships. The students' work experiences are used for developing generic skills and knowledge, as described in the generic model of work experience of Guile and Griffiths (2001). However, general subject matter is often separated from practical vocational skill teaching. In our research project we examine the quality of the learning outcomes in educational situations in which subject matter theory and vocational skills are integrated, following a design-based research approach (Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004; Shavelson, Phillips, Towne, & Feuer, 2003; The design based research collective, 2003). An earlier case study showed that students can, given practical problems in the vocational workshops[14], be guided towards a theoretical understanding of codified knowledge (Van Schaik, Van Oers, & Terwel, 2010a). The study in question demonstrated that a design and construction assignment may be potentially knowledge-rich. However, knowledge remained situated. The

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[13] In this article pre-vocational education will be used to refer to the Dutch preparatory senior secondary education, VMBO.

[14] The vocational workshops are the practice classes in which the skills and attitudes are practiced.

assignment used in the case study was redesigned for a first intervention, from which we learned that explicit attention to models as tools resulted in a better understanding of models (Van Schaik, Van Oers, & Terwel, 2010b).

For the present study, the intervention was adjusted for four new schools, with a special focus on more explicit connections between product design and appropriation of subject matter knowledge. Students were asked to design and build a prototype tandem tricycle. Teachers subsequently assisted the students in dealing with problems during the tricycle design and production stages. The students were encouraged to use or develop models to solve the problems they encountered in working on this 'real-life' assignment. As we learned from the previous studies, stimulation in the practice workshop is insufficient for the reconstruction of subject matter knowledge and models on the basis of practical problems alone. In that light, we created a series of 'prototype lessons', during which students were guided to move from practical solutions and drawings to codified subject matter knowledge and models.

Theory and practice in pre-vocational education

By way of an attempt to improve the relevance of knowledge and the effectiveness of knowledge transfer to the workplace, as is the case in other countries, a reform is taking place in Dutch pre-vocational schools (Guile & Young, 2003; Seezink & Van der Sanden, 2005). One of the proposed reforms envisions the teaching-learning process as an activity embodied in a simulation of real world practices. Students work on products for 'real' customers and in this context they are guided by teachers to acquire knowledge and skills. The basic assumption behind this approach is that learning of codified knowledge and vocational skills can be integrated into authentic workshop practices. The pedagogical approach can be characterised as what Tynjälä (2008, p. 144) calls "integrative pedagogics". However, working on a (practical) problem is not enough to motivate students to learn (Guile & Young, 2003), and participating in real life situations is insufficient to develop higher level expertise (Tynjälä, 2008). The challenge for schools is to design assignments that are meaningful for the students and relevant to their future jobs (Tuomi-Gröhm & Engeström, 2003; Volman, 2006). At the same time, assignments should also result in highly qualified learning outcomes that enable students to recontextualise their knowledge and skills from the classroom to the workplace. In short, teaching should support students in relating practical problem solving to codified curriculum knowledge (Guile & Young, 2003; Van der Sanden, Terwel, & Vosniadou, 2000). From this perspective therefore, students need to be supported when solving real life problems with "conceptual and pedagogical tools which makes it possible for them to integrate theoretical knowledge with their practical experiences." (Tynjälä, 2008, p.145).

In our previous studies we investigated this process in detail (Van Schaik, Van Oers, & Terwel, 2010a), exploring the implementation of two assignments and the subsequent teacher guidance at one school and testing whether or not the learning environments had become knowledge-rich (Guile & Young, 2003). We considered the environment knowledge-rich when it had the potential for students to acquire knowledge which was codified or disciplinary. It turned out that designing a tandem tricycle can, in fact, create opportunities in teaching students codified knowledge and modelling. The present study builds on those findings in a larger experiment. The general issue was: is it better to provide students with models, or have them construct the models themselves collaboratively under guidance? From a sociocultural point of view, there is reason to believe that the latter method will result in improved learning outcome. This is supported by the outcomes of various studies. For example, Terwel, Van Oers, Van Dijk and Van Eeden (2009) found that in primary education students obtain a better understanding of modelling when they are actively involved in the design of models. Gresalfi (2009) concludes that when students have to explain their use of mathematical concepts in collaborative practices, they get more deeply involved with the content. These "collaborative practices are simultaneously important to productive dispositions, conceptual understanding, and preparation for future learning" (Gresalfi, 2009, p. 363).

Models as tools

In pre-vocational education students both design and construct real products. During the design and construction processes problems arise that need to be solved. Models may be used to anticipate possible problems and their solutions. Although drawings and models are important in design technology and serve to communicate and generate ideas, MacDonald & Gustafson (2004) claim that classroom emphasis is merely on their representational function. Students must be able to draw correctly, while their models, including assessment, are used for teacher diagnostics only. If students' classroom drawings were preceded by students' orientation towards the problem situation and the exploration of ideas, modelling might develop into an active learning strategy which could help students gain deeper understanding of problems and their possible solutions. This assumption is in line with the view of Tuomi-Gröhn and Engeström (2003). Rather than primarily having a diagnostic and explanatory function, models serve a dual purpose:

"On the one hand, the practitioners model the past and present contradictions in their activity system in order to understand where the causes of trouble lie and on which aspects of the activities they shall focus their change efforts. On the other hand, the practitioners model also a future vision of their activity, in which they depict expansive solutions to the contradiction." (Tuomi-Gröhn & Engeström, 2003, p. 32).

In this article models are defined, following Van Oers's (1988), "... as any material, materialised (for example a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's action ..." (p.127). These models function as tools in orientation and communication activities, in ways similar to those described by Tuomi-Gröhn & Engeström. For example, a model may allow the designer to calculate angles in a drawing in advance, so that steel may be sawn correctly in one single process, rather than by trial and error. Here the mathematical formula functions as an orientation tool. When, with regard to the present context, the drawing is used by students to negotiate the design of the tricycle with others, it also becomes a tool for communication. Hence, orientation and communication are both functions of a model, which can consequently serve both at the same time.

Disciplined perception

Modelling in the vocational education practice workshops can serve both students' technical codified knowledge and the more general knowledge in subjects such as mathematics and science. When models as well as the accompanying planning solutions are used as means for orientation and communication in relation to present and future problems students' disciplined perception may develop (Stevens, 1998). This implies that students become familiar with the modes of thought that prevail in the discipline. In pre-vocational education the disciplines comprise both general curriculum subjects (derived from academic disciplines such as mathematics and science) and vocational disciplines, in our case those in the technical and technological domains. Students should be supported to "... gain a greater awareness and appreciation of the discourse repertoire … and how it is used to create knowledge and to get things done" (Mercer, 2002, p. 147). They are therefore required to actively construct knowledge and information, applying the system of artefacts used in the practice of the discipline (cf. Beach, 2007). However, according to Stevens and Hall, "disciplined" also implies that "learning to participate in disciplinary practices does not depend solely on 'instruction and exercise'..." (p.109). On the other hand, participation and working on authentic assignments alone is not sufficient either in attempts to acquire an understanding of modelling and codified knowledge. Obviously, for developing disciplined perception we need to avoid a strict opposition between unguided discovery learning, minimally guided learning and direct instruction (e.g., see Kirschner, Sweller, & Clark, 2006), or between providing and generating teaching-strategies (Rosenshine, Meister, & Chapman, 1996).

Guided co-construction

In the above light, modelling should become a strategy to solve problems, with teachers assisting students in their attempts to understand the potential problem solving function of models; in other words, assisting students in understanding the orientation and communication function of models, as opposed to their mere representational function. Drawings and models should not only be viewed as subtasks without any relation to the final goal of designing.

By collaboratively reflecting on and improving the production process, participants learn to understand the often tacit rules and codes of the workplace and the knowledge underlying them (see also Lave & Wenger, 2005). As tools for communication and orientation models may assist students in thinking ahead and reflecting on their own process and product. Students' understanding may increase as a result. On this view the teacher's role is to support reflection on the models and thus to discursively guide the students in their process of (re)constructing the appropriate models that optimally serve both functions for the task in hand. Guiding in a co-constructive way thus means helping students to collaboratively reconstruct models and subject matter knowledge through an ongoing and reciprocal discursive process, focused on the solution of task-related problems. It is the teacher's role to "… maintain connections between the curriculum-based goals of activity and a learner's existing knowledge, capabilities and motivations" (Mercer, 2002, p. 143). Research has shown that the instructional strategy of guided co-construction may lead to a better understanding of mathematics and modelling than a strategy based on models that only provide (Doorman, 2005; Terwel, Van Oers, Van Dijk, & Van Eeden, 2009; Van Dijk, B. Van Oers, & Terwel, 2003). Mercer (2002) summarises the characteristics of teachers who were successful in supporting pupils in their development of mathematical problem solving and reading comprehension. Above all, such teachers use questions "not just to test knowledge, but also to guide the development" (Mercer, 2002, p.144). Secondly, the teachers taught more than subject content. They also assisted students in understanding the problem-solving strategies and making sense of their experiences. Finally, "they treated learning as a social, communicative process" (ibid.). All of these characteristics are elements of what we call guided co-construction. In contrast to a providing form of teaching, in which knowledge, concepts and models are provided as ready-made solutions, guided co-construction may lead to a better understanding of modelling.

In our second study, which comprised interventions at two schools, a programme based on the tricycle assignment was designed and teachers were trained to guide the students either in a co-constructive way or in a providing way (Van Schaik et al, 2010b). It turned out that the younger students in the co-construction conditions produced better product models.

In this article we present a collaborative practice, in which students were asked to design and build a prototype tandem tricycle. Our research question is the following: by designing a real product themselves, do students, under co-constructive guidance, gain codified knowledge in mathematics and science and a better understanding of modelling? From the theoretical basis mentioned earlier we expected that co-constructive guidance and a purposeful use of models as creative thinking tools, students would perform better on a post-knowledge and modelling test than students who were provided with preformatted models and knowledge. This led to the following hypothesis: Students in the experimental condition will outperform their counterparts in the control condition on the scores of the post-tests.

Method

Intervention

The intervention design was primarily based on experiences from the two earlier studies (Van Schaik, Van Oers & Terwel, 2010a; Van Schaik, Van Oers & Terwel, 2010b), which revealed that designing and building a tandem tricycle may evoke the use of models and technical knowledge, and that guided co-construction in this process improves the quality of student models. As part of a design research project, we wanted to study the intervention in authentic contexts (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The four schools involved were allowed to effect local adjustments in order to maintain their school culture, thus keeping the ecology as authentic as possible. We agree with Lemke and Sabelli when they point out on the basis of complex systems theory that “Adaptation of models for system reform to local conditions matters more than efforts to replicate success elsewhere” (2008, p. 125). Although our intervention is not a system reform, we acknowledge that the design used in previous studies needs to be adaptive to the local conditions of the schools in this study. In effecting local adjustments the agency of the participants was respected and, as a result, the programme changed when used as a tool by the participants. An appropriate way to characterise our method would be to place it in the tradition of formative intervention (Engeström 2007; 2009). The complexities involved in studying different school practices were also acknowledged (Goodlad, Klein, & Tye, 1979). We therefore follow Downing-Wilson, Lecusay & Cole (in press) in that, on the basis of joint activity with the teachers, the intervention was interpreted and changed by all parties involved, so that schools were assigned to the condition with which their current practice was most in line. Schools that tended to teach students theory and models in a providing fashion were assigned to the control condition. Schools that already had a teaching-learning practice that resembled guided co-construction were assigned to the experimental condition. Since we analysed the "design as implemented" (Ruthven, Laborde, Leach, & Tiberghien, 2009, p. 341) and adopted the "enactment perspective" to examine the implementation (Snyder, Bolin, & Zumwalt, 1992, p. 418), the intervention itself evolved as a result of our research interactions. Hence, details concerning the way the intervention actually developed are reported in the results section.

The intervention consisted of a student assignment (see below) plus an educational instrument for the teachers. The instrument was subsequently adjusted to the two conditions. It consisted of a series of embedded prototype lessons and examples of problems that students might encounter in design and construction processes. The teachers were supposed to pay explicit attention to the way students' situated knowledge was related to more general knowledge; moving from practical problems to modelling by the use of mathematical and scientific concepts. The prototype lessons were the instructional moments for reflection on the practical problems and their underlying principles.

The differences between the conditions concerned the way modelling was introduced. In the control condition the models were to be ready-made and provided as solutions to students' problems. In the experimental condition the students were stimulated to design or (re) construct the models collaboratively, while lessons or instructional moments were organised in situ.

Participants

87 15-year-old students from four schools participated in the present study. With the exception of School 2, where all students that participated were staff level, students worked in mixed groups of the two lowest learning tracks, basic and staff level, during the practice classes[15]. Schools were assigned to the condi-

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[15] In VMBO students are divided among four 'learning tracks'. They differ in the theoretical level of the subject matter. The four levels are: 'basic level' (lowest theoretical level); 'staff level' (second theoretical level); 'mixed level' (intermediate theoretical level); theoretical level (highers theoretical level).

tion that best fitted their practice, as assessed during the initial visits and team interviews.

Schools

Experimental school 1: Peter Willems College

This school was assigned to the experimental condition. It had 33 students in 11 groups of three working on the project. Students worked in a large central workplace area with a computer room in the middle and two classrooms on the side, available for theoretical instruction. Sometimes the computers were used for information searching. Drawings were mostly constructed by hand. Subject matter teachers were sometimes present in the workspace, but did not integrate the practical assignment into their lessons. One senior teacher guided the students most of the time and graded them. Other teachers and classroom assistants helped students with practical problems. The project for the students finished at school with a peer presentation. The school did not follow the prototype lessons plan. It scored below average for the total sample (see table 2) on two of the three pre-measures (see section instruments & procedures).

Experimental school 2: Technical College Oldenhave

Technical college Oldenhave was assigned to the experimental condition. Four groups of four students out of a class of 24 chose to work on the assignment (two other groups worked on other authentic assignments). Students worked in two spaces: one, their 'own', with computers and some technical equipment, and one reserved for metal working (i.e. grinding, sawing metal and welding). The students were guided by a team of four teachers, both subject matter and practice teachers. Students used subject matter classes for their ' theoretical' problems. The content of the prototype lessons was taught in situ. Students used computers with 2D and 3D Computer Aided Design (CAD) software for their drawings. The project ended with a presentation to their peers. The mean scores of the students on all pre-measures were higher than those for the other schools.

Control school 3: Prince of Orange College

The third school was assigned to the control condition. 23 students worked on the assignment in five groups of mostly four. They worked in a big open workplace with technical equipment and computers available. Subject matter classes were sometimes held in the small classrooms bordering the main space, sometimes in other parts of the building. One group was observed using the computer to draw a draft. The students had been trained to use CAD software. One teacher guided the group, while subject matter teachers were rarely seen in the workplace. One prototype lesson out of five was taught without the assigned mathematics teacher present. The scores of two of the three pre-measures were below the sample mean.

Control School 4: Orthen Technical School

This school was assigned to the control condition and had 15 students working in five groups of three. The workshop space was large and had recently been refurbished. Computers and a separate instruction space were available. Students were guided by two practice teachers and one teacher who taught the prototype lessons and normally functioned as a welding teacher but who used to be a mathematics and physics teacher. Computers with 2D-CAD software were used for the drawings. Prototype lessons (three out of five) were taught separately to the whole group. This school scored above the sample mean on two of the three premeasures.

Student assignment

Signs as well as relevant science and mathematics subject matter. Models were used either in a providing way (in the control condition) or in a co-constructive way (experimental condition). For the students the process started with an introduction by the researchers, who explained the purpose of the assignment, which was to build a prototype to win a competition. The students started designing during the first week (see figure 5.1 for an example) after which they moved on to construction in the weeks following. The competition ended initially with the selection of the two best prototypes at every school, which was followed by a final session during which a jury decided which prototype was the best (figure 5.2).

Teachers' educational instrument

A teacher instrument was developed which consisted of a series of embedded prototype lessons and examples of problems that students might encounter during the design and construction processes. The instrument differed according to the way the students in the two conditions had to be guided. For the experimental condition the instrument consisted of a 'toolkit' with possible content for prototype lessons and templates for ad hoc lessons and instruction. The toolkit was intended as a reference base for the teachers. For the control condition the instrument consisted in a detailed lesson plan for the teachers to follow.

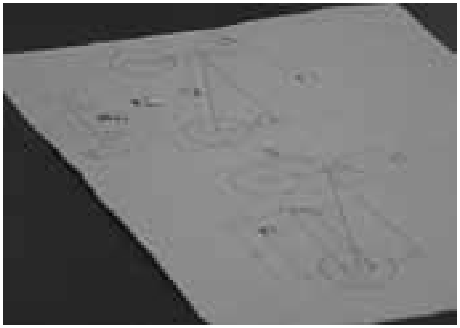
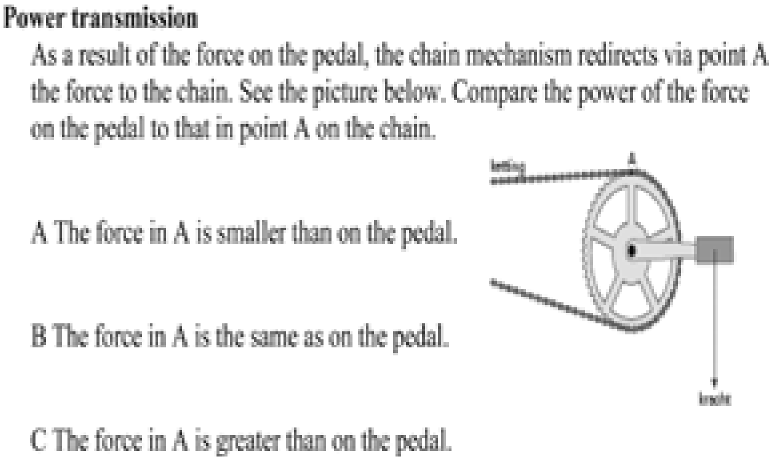


Figure 5.1 Students' design in the control condition (video still)

Figure 5.2 The winner tricycle of the competition chosen by the jury of experts.



Power transmission

As a result of the force on the pedal, the chain mechanism redirects via point A the force to the chain. See the picture below. Compare the power of the force on the pedal to that in point A on the chain.

A The force in A is smaller than on the pedal.

B The force in A is the same as on the pedal.

C The force in A is greater than on the pedal.

Figure 5.3 Power transmission about here

Instruments and procedure

To measure the students' pre-knowledge, nonverbal reasoning, and vocabulary, we administered several tests. First, knowledge and understanding of mathematics and science modelling was measured in a pre-test. The test consisted of 20 items. 17 items were derived from national examinations for the testing of mathematical, scientific and technical knowledge. The three final test tasks were semi-structured drawing items, including ways of building a cart engine plus an accompanying visualisation task (see figure 5.4). The post-test was almost identical to the pre-test. The maximum score was 47 points. Cronbach's alphas were 0.75 for the pre-test and 0.73 for the post-test. A sample national exam item is depicted in figure 5.3.

In addition we administered a national vocabulary test with a reported alpha of .89 (N=2200). The vocabulary test was administered by means of computers. Finally, Raven's Standard Progressive Matrices test was conducted to measure the students' non verbal reasoning and general factor of intelligence with a reported test-retest coefficient of .88 (J. Raven, J.C. Raven, & Court, 2000).

To follow the implementation of the programme, all the participants, including teachers and students, were interviewed during and after the intervention. In addition, lessons and workshops were video-recorded using a three-camera approach: two fixed cameras recorded the entire classroom from different angles, while a one hand-held camera recorded interactions between students and teacher (Clarke, 2004; Van Schaik, 2009; Van Schaik et al.2010a).

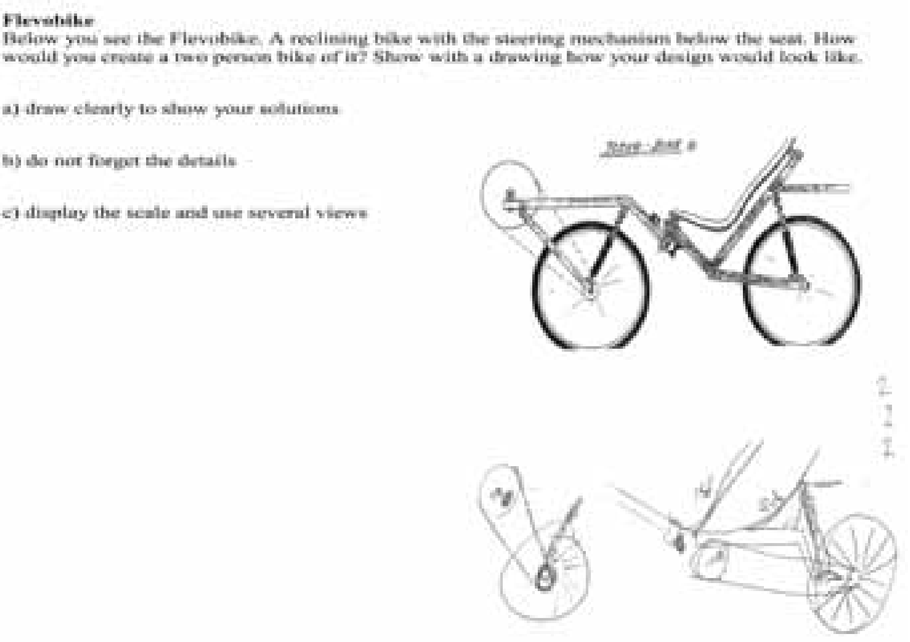
Results

We will first report on the results of the variables as tested by the pre- and post-tests, followed by a description and analysis of the design as implemented.

Table 5.1 shows the overall scores for all the tested variables. Only vocabulary shows significant differences between the conditions. Students in the control condition scored considerably lower (62.41) on the test in question than those in the experimental condition (70.93).

Scores on all tested variables for every school are displayed in table 5.2, arranged by the two conditions and the four schools. The table shows that School 2 has the highest mean score on the post-test.

Correlations were computed to examine possible relations between the variables. As table 3 shows, the pre-test is positively correlated with the post-test.



Flevobike

Below you see the Flevobike. A reclining bike with the steering mechanism below the seat. How would you create a two person bike of it? Show with a drawing how your design would look like.

a) draw clearly to show your solutions

b) do not forget the details

c) display the scale and use several views

Figure 5.4 Modelling test item in about here

Table 5.1 Overall descriptive statistics of the pre- and post-measures: overall and by condition

	N	M	SD	Min	Max
Overall	**87**				
Age (in months)	87	192.72	7.56	168	212
Vocabulary	76	67.34	12.31	39	101
SPM	80	42.50	8.21	0	54
Pretest*	82	18.17	8.30	4	35
Posttest*	73	20.45	7.74	4	35
Control condition	**38**				
Age (in months)	38	192.95	7.32	180	212
Vocabulary	32	62.41	11.51	39	81
SPM	34	43.38	9.07	0	53
Pretest*	35	18.40	8.03	4	33
Posttest*	31	20.81	7.66	5	35
Experimental condition	**49**				
Age (in months)	49	192.55	7.82	168	205
Vocabulary	44	70.93	11.73	39	101
SPM	46	41.85	7.55	17	54
Pretest*	47	18.00	8.58	5	35
Posttest*	42	20.19	7.88	4	33

* Maximum score on pre- and posttest is 47

Nonverbal reasoning, the general factor of intelligence (SPM) and pre-knowledge are all positively correlated. The variable vocabulary is correlated with SPM (positive) and condition. Students in the experimental condition scored lower on vocabulary.

The table shows there is no correlation between condition and learning outcome. An independent t-test confirmed this (see table 5.4).

The differences between all schools on the post-test were measured by means of ANOVA: $F(3, 69)= 18.31$, $p= .00$. A one-way analysis of covariance (ANCOVA) was subsequently conducted to examine the way the covariates were related to the independent variable school. The dependent variable constituted the score on the post-test and the covariates the score on the pre-test the vocabulary test and the SPM. A preliminary analysis to evaluate the homogeneity-of-slopes assumption indicated that the relationship between the covariates and the dependent variable did not differ significantly as a function of the independent variable, $F(3,44)=. 38$, $F(3,44)=1.95$ and $F(3,44)=.38$, $MSE=23.31$, with respectively $p=0.77$, $p=.13$, $p=.77$ and partial $\eta2=0.25$, $\eta2=.12$ and $\eta2=0.25$. ANCOVA was significant, $F(3,53)=1.07$, $MSE=23.91$, $p<0.01$. The strength of relationship between the schools and the dependent variable was medium as assessed by partial $\eta2$ with the school factor accounting for 6 per cent of the variance of the dependent variable, with the pre-test scores, vocabulary and SPM held constant.

The adjusted means of the post-test scores by school are depicted in table 5. These adjusted means were evaluated against the pre-test, vocabulary and SPM. As can be calculated from the last column of table 5.5, the differences between schools on adjusted post-test scores ranged from 1.86 to 4.46 points (see table 5.5). School 4 shows the largest adjusted mean (M=22.96), School 2 the second highest (M=21.15), while School 3 had a somewhat smaller mean (M=19.30) and School 1 the smallest mean (M=18.50). Follow-up tests were conducted to evaluate pairwise differences among the adjusted means. The Holm's sequential Bonferroni procedure was used to control for Type I error across the six pairwise comparisons. No significant differences in the adjusted means between the pairs of schools were found.

No significant difference was found between the two conditions on post-test scores and no school from either one of the conditions differed significantly from the others. Our hypothesis that the experimental condition would outperform the control condition must therefore be rejected. Moreover, it should be noted that School 4 students scored very low on vocabulary (M=57.82) and that School 2 scored high on all pre-measures. In general, students scored approximately 50

Table 5.2. Descriptive statistics of the pre- and post-measures for every school

	N	M	SD	Min	Max
Experimental group	**49**				
School 1	**33**				
Age (in months)	33	193.85	8.01	168	205
Vocabulary	30	69.03	11.91	39	98
SPM	30	38.83	7.04	17	50
Pretest*	32	13.81	6.54	5	28
Posttest*	26	15.96	6.10	4	26
School 2	**16**				
Age (in months)	16	189.88	6.88	181,00	203,00
Vocabulary	14	75.00	10.59	63	101
SPM	16	47.50	4.77	37	54
Pretest*	15	26.93	4.66	21	35
Posttest*	16	27.06	5.17	16	34
Control group	**38**				
School 3	**23**				
Age (in months)	23	193.74	6.99	180	204
Vocabulary	21	64.81	9.71	43	81
SPM	19	42.32	11.45	0	53
Pre-test*	20	14.07	7.57	4	28
Post-test*	16	16.25	6.18	5	29
School 4	**15**				
Age (in months)	15	191.73	7.88	180	212
Vocabulary	11	57.82	13.65	39	81
SPM	15	44.73	4.65	35	49
Pretest*	15	23.33	5.75	14	33
Posttest*	15	25.66	5.98	16	35

* Maximum score on pre- and posttest is 47

Table 5.3 Correlations (N=87, pair wise)

	Age	Voc	SPM	Pre-test	Post-test	Cond	School
Age (in months)		-0.58	-.143	-.065	.116	.026	-.195
Vocabulary			.251*	.119	.168	-.344**	.056
SPM				.373*	.169	.093	.405**
Pre-test					.771**	.024	.627**
Post-test						.040	.622**

** Correlation is significant at the 0.01 level (two-tailed)

* Correlation is significant at the 0.05 level (two-tailed)

Table 5.4 Results of the experimental group (N= 49) compared to the results of the control group (N=38) on the knowledge and modelling test.

Condition	Mean	SD	df	F	t	p
Experimental	20.19	7.88	71	2.28	-.334	.74
Control	20.81	7.66	65.82			

per cent on both the pre- and post-tests (respectively M=18.17 and M=20.45 out of 47) and, although the tables do not show this directly, some students even showed a decrease in the score on the post-test. This was especially true for the students at School 2. At that school students' mean score on the pre-test was very high. Compared to the other schools, however, the mean post-test score increase was only .13 points. Differences of pre-measures and adjusted post-test scores are displayed in table 5.5. In conclusion, we did not find any statistically significant differences between the conditions and (pairs of) schools.

We now turn to an analysis of the school implementation process.

Analyses of intervention as implemented

Since the variable school explained 6 per cent of the variance, the next step in our analyses was to find the characteristics of the schools that could explain the differences in outcome. For that purpose we analysed the way the schools enacted the design, guided by an examination of logs, observations and interview data.

We first analysed the logs that were kept by the researchers during the school implementation part of the project. We found that schools differed in how well they followed the guiding tool; that is, how the intervention was carried out compared to how it was originally designed. School 2 and 4 implemented the intervention most closely to the intention, following the teaching of the prototype lessons in accordance with their condition guidelines. However, they did not fully implement all the lessons suggested. School 1 and 3 did not teach the prototype lessons at all.

Second, from the interviews with the students and teachers we learned the extent to which the project differed from the way assignments were normally carried out. At School 1, 3 and 4 the main difference lay in the fact that students normally work alone. For the tricycle assignment students could make their own decisions on how to proceed with the design, whereas they would normally follow a fixed procedure for other assignments. In the words of one student: "You couldn't do anything wrong … you simply could chose whatever you wanted [on how to construct]." Students at School 3 mentioned that the size of the assignment was also greater than normal. At School 4 students were used to having a drawing provided and constructed only smaller components, instead of something which, in the words of one student, "will really be used." The only difference with regular practice at School 2 was that this time the assignment was not for a 'real' client, but for a competition. In their regular practice students also have a client, an assignment and a budget, and proceed from there.

From the interviews it also became clear that a subject-matter teacher was involved when students worked in the workshop at only two schools (2 and 4). Of

Table 5.5 Initial mean scores and adjusted means post-test scores by schools

	Vocabulary	SPM	Pre-test	Adjusted post-test
Experimental group				
School 1	69.03	38.83	13.81	18.50
School 2	75.00	47.50	26.93	21.15
Control group				
School 3	64.81	42.32	14.07	19.30
School 4	57.82	44.73	23.33	22.96

Table 5.6 Teacher-student ratio at the four schools.

	Teacher:student	Ratio
School 1	3:33	1:11
School 2	4:16	1:4
School 3	1:23*	1:23
School 4	3:15	1:5

* At School 3 there was a change of the second teacher during the project, therefore most of the time only one teacher was present.

the teachers at School 2 who guided the students, two also taught mathematics or physics, although not to students in the project. At school 4 the teacher who taught the prototype lessons had formerly been a mathematics and physics teacher and normally taught welding.

Finally, after a first view of the observational data we noticed that the number of subgroups and students present in a classroom differed considerably. The teacher-student ratio at School 3 was 1:23, whereas at School 2 it was 1:4 (see table 5.6). The observations also showed that students were not stimulated to use Computer Aided Design (CAD) software for drawings at every school. Only at school 2 and 4 all subgroups used computers to create CAD drawings before starting their tricycle constructions. At School 3 only a few groups succeeded in drawing their models in CAD.

The overall conclusion from the test data and the first analyses of the qualitative data must be that the condition to which the schools were initially assigned could not explain the differences in post-test scores. The differences found were small and not statistically significant. School 4 scored highest in the post-knowledge and modelling test, which was adjusted for initial differences. At that school the implemented design was close to the intended control condition design, but differed considerably from normal practice at the school. The teacher-student ratio was 1:5. School 2 had the second highest score on the post-test. However its students scored high on the pre-test and the teacher-student ratio was 1:4. The intervention at that school showed the most similarities with normal assignment practice. Finally, at Schools 2 and 4 a subject matter teacher was closely involved in the workshop practice lessons and students were more familiar with CAD software in drawing their construction plans.

Conclusion

The study was aimed at examining the way in which students, while designing and constructing a tandem tricycle for small children, gained not only knowledge codified in the subjects of mathematics and science but also an understanding of models. The assignment was implemented at four schools, in two conditions. In the experimental condition teachers guided the students in a co-constructive way, assisting students in the reconstruction of collaborative models and subject matter knowledge by means of an ongoing and reciprocal process. In contrast to a more traditional form teaching, in which knowledge, concepts and models are provided in the form of ready-made solutions, guided co-construction may lead to a better understanding of modelling. The research question was: by designing a real product themselves, do students, under co-constructive guidance, gain codified knowledge in mathematics and science and a better understanding of modelling?

From the perspective of our theoretical framework it was expected that when guided in a co-constructive way, plus the use of models as creative thinking tools, students would perform better on a post-knowledge and modelling test than students who were provided with preformatted models and knowledge. This expectation produced the following hypothesis: students in the experimental condition outperform their counterparts in the control condition on the scores of the post-test.

Data analysis led to the conclusion that our hypothesis must be rejected. Students in the experimental condition did not outperform their counterparts in the control condition. Nor, after controlling for initial differences, were any differences between the schools found. Although the 'best' performing school was in the control condition, condition was not the factor that explained the difference on the post-test. A comparison between the schools did not result in a significant difference between schools. Schools 2 and 4 had the highest adjusted scores on the post-test.

Analyses of the design implementation produced clues that might explain the small differences in the results. The two schools (2 and 4) that showed the highest scores on the post-test were schools with practice teachers who had a background in mathematics or science, and a higher teacher-student ratio than the other schools. In addition, the students at the schools in question used CAD software to draw their constructions models, while the implemented intervention was closest to the intended intervention. The most plausible explanation here is that a high teacher-student ratio plus the presence of a subject matter teacher in the workshop resulted in the higher scores.

Discussion

We agree with Gresalfi (2009) that collaborative practices and the meaning-creating opportunities they afford are important for learning. However, Dutch pre-vocational education differs from other systems in that it has a dual focus, directed towards vocational knowledge and skills as well as on general codified knowledge derived from the academic disciplines. According to this view, collaboration on authentic assignments alone is insufficient to integrate skills and disciplinary knowledge. The missing collaborative factor is the teacher, who is required to support students in relating practical problem solving to codified curriculum knowledge (Guile & Young, 2003; Van der Sanden, Terwel, & Vosniadou, 2000).

At all four schools in our intervention students collaborated on tricycle design and construction. At two schools (school 2 and 4) where teachers had the opportunity to intensively guide the students from situated problems to codified knowledge students scored slightly better on the post-test than their counterparts at the other schools. On the post-test the scores on average were between 38 and 43 per cent, students at School 2 and 4 however scored above 50 per cent. Since the test consisted of items of previous final exams, the students at these schools may have been already at the requiered final exam level, whereas the students at the other schools were not. The fact that workplace teachers at the schools in question had backgrounds in the relevant academic disciplines might be taken to suggest that teachers in those classrooms used conceptual and pedagogical tools to integrate subject matter theory (Tynjälä, 2008). Also, students at the two best performing schools used CAD software for there drawings. This software forces the students to model like designers, in ways similar to normal practice in their future occupations. In other words, with the support of academically trained teachers, the students' disciplined perception may have been enhanced, in the following two ways (Stevens & Hall, 1998). First, students assumed the role of workers in their discipline (vocation). Second, they learned to see the connection between practice and theory: they not only practised their vocational skills in the workplace, but were, in addition, trained to use the models as tools for problem solving both in vocational practice and in the academic disciplines that were reflected in the curriculum subjects. Further research will have to focus on the micro level to examine the enhancing effect of CAD software use on disciplined perception. In addition, it needs to be noted that students at School 2 and 4 scored relatively high on the SPM-test, which is a rather perceptual test for non-verbal reasoning, although statistically this variable was not significant.

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 schooling domain. As a consequence the implementation of the design differed considerably among the schools. Since groups of students and teams of teachers 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 on one side the researcher(s) and on the other the teacher(s) (Downing-Wilson, Lecusay & Cole, in press).

Further research might, by means of micro-analyses, confirm the teacher characteristics that Mercer (2002) found at well-performing primary schools. We refer here specifically to the assistance given by the teachers at School 2 and 4 by which students are given greater insight into disciplinary problem-solving strategies. Such teacher guidance may help students make sense of their experiences in relation to the knowledge codified in subject matter and in the practical domain. Especially at School 4, in spite of students' low scores on vocabulary, the teacher guided the students to relatively high scores on the post-test. It would be interesting to find out to which of Mercer's rather conversational characteristics this teacher guidance complies to. This type of guidance might be instrumental in attempts to overcome the dichotomy between unguided or minimally guided instruction and direct instruction (Kirshner et al., 2006), or the dichotomy between generating and providing (Rosenshine et al., 1996).

The present study suggests three factors that may improve student's modelling and understanding of models: teacher-student ratio, teacher's academic background and explicit attention to modelling in the form of prototype lessons. Furthermore, we have seen that the intervention as implemented differed dramatically among the schools. In that light, we need to take a closer look at contextual school factors and school cultures that may influence design implementation. For example, the students at School 2 scored better on the pre-tests, as a result of which the classroom culture at that school may be more stimulating. On the other hand, students on School 4 scored low on vocabulary, but also performed well on the post-test. We therefore need a deeper understanding of guided co-construction as a teaching strategy in vocational education.

Further research will be required to examine the nature of teacher-student micro-processes and the tools used in problem-solving processes.

6.

Modelling in simulated workplaces*

Abstract

In this study we report on a multiple case study conducted at four prevocational education schools where curriculum projects were implemented. The main focus is on examining ways in which student modelling fosters students' understanding of codified knowledge and how models are designed and used in processes of guided co-construction in the technical domain. The study is a qualitative analysis of a third iteration design-based research project, in which students had to design and construct a tandem tricycle. The data consisted of video observations and interviews as well as test data. The conclusion was that each school enacted its own version of the intended curriculum project and could be characterised by a unique overall pattern of interaction. Professional designer practice was reflected best at two schools, where, in fact, students also performed better. For the schools in question we have reason to assume on the basis of students' increased understanding that students developed a sense of *disciplined perception*. Models at those schools were part of the entire design and (re-)construction process. We conclude that modelling is an activity which, in a process of guided co-construction, can enrich practical assignments with the theoretical concepts of mathematics and science.

* This chapter will be submitted as an article.

Modelling in simulated workplaces

In workplace simulations in vocational education students often work on real customer assignments and products. The process focuses, first, on timely delivery, second on the acquisition of necessary skills and only in the last resort on the development of understanding. In this paper we argue that modelling should be regarded as the pivotal activity during practical assignments by which the understanding and integration of general curriculum subject matter can be enhanced.

The present study is a qualitative analysis of a third iteration design-based research project (Bell, 2004; Cobb et al., 2003; Collins et al., 2004). Previous studies in our project have shown that designing and constructing a real product in preparatory vocational secondary education (VMBO)[16] has the potential of being knowledge-rich and improving the understanding of mathematical and scientific concepts. However, in the process the outcomes of previous research became ambiguous. The first case study (Van Schaik et al., 2010a) enabled us to determine the learning potential of an assignment whereby students had to construct a tandem tricycle. The assignment was knowledge-rich in that it created opportunities to make connections between the students' available situated knowledge and the codified knowledge of mathematics and science (see Guile & Young, 2003). However, it was difficult to move from situated knowledge to the more general forms of knowledge codified in curriculum subjects (see also Nijhof & Nieuwenhuis, 2008). The first quasi-experimental intervention (Van Schaik et al., 2010b) showed that students who used models as open-ended design tools created better models. However, the knowledge gained in either condition was the same. In the most recent experiment (Van Schaik, et al., submitted a) quantitative data from pre- and posttests produced evidence that both knowledge and understanding on modelling improved when students worked on a design and construction assignment in a curriculum project. However, of the two schools that scored best on the tests, one was in the experimental group, the other in the control group. The significant differences occurred at school level, rather than that of the research conditions. Consequently, the hypothesis that the shaped conditions would differ in outcome could not be confirmed. In the present study we will look more closely at how student modelling enhances the understanding of codified general curriculum knowledge. More specifically, we will examine the role of models in the design process.

Modelling in vocational education workshops can serve both students' techni-

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[16] VMBO in the Netherlands is preparatory secondary education with a vocational perspective. See (Cedefop 2009, Maes 2004). In this article vocational education refers to VMBO.

cal codified knowledge and the more general knowledge codified in subjects such as mathematics and science. In contrast to simply looking at a technical artefact or making a practical construction, collaboratively designed models may create a new dimension during the construction process that uncovers the basic structure of the emerging construction. This new dimension creates *insight* into the way the elements relate to each other and how technical artefacts work, for example a tricycle (cf. Verkerk et al., 2007). As a result, the students are able to see the tricycle not only as a working means of transportation, but also conceive of it as a concrete specimen of the transmission of forces.

In addition, as the product is finished, the steps in the design process can be traced back by looking at the earlier sketches or models used in the design and construction process. From this reiterative reflection process understanding and codified knowledge may emerge by which the design process is made explicit and the final product transparent. Put differently, the blackbox of a technical product opens up and a *knowledge-rich* situation is created by students and teachers alike. The elements, concepts, insights and procedures can be used not only to reproduce the same construction but also to inspire a new design, as for example the transmission principles and gearwheels for a clock or a bicycle. Ultimately, it is insight into the basic structure that enables recontextualisation in new situations. In other words, it is not so much construction but reconstruction that is the key to understanding and to the appropriation of codified curriculum knowledge: 'It is continuous reconstruction, moving from the child's present experience out into that represented by the organized bodies of truth that we call studies' (Dewey, 1981;1902, p. 472).

Once models are used as a means of orientation and communication in relation to present and future problems and planning solutions to such problems, students may develop *disciplined perception* (Stevens & Hall, 1998). This means that students become familiar with various modes of understanding a discipline or a particular practice, moving from perception to conceptual and strategic thinking. In vocational education the relevant disciplines are academic, in the form of general curriculum subjects (derived from academic disciplines such as mathematics and science) and vocational, in our case the technical and technological domains. Students should be supported to '... gain a greater awareness and appreciation of the discourse repertoire [of the domain] … and how it is used to create knowledge and to get things done' (Mercer, 2002, p.147). Consequently, they need to actively construct knowledge through the practical system of disciplinary artefacts (cf. Beach, 2007). Hence, 'disciplined' also implies that ' … learning to participate in disciplinary practices does not depend solely on 'instruction and exercise ...'(Stevens & Hall, 1998, p.109). Students need explicit support in the reconstruction of disciplinary concepts, models and methods. Since learning to participate in practical contexts cannot depend on instruction, and given that students need to actively construct knowledge, we need to overcome the distinction between unguided discovery learning and direct instruction (Kirschner et al., 2006); between a providing strategy and a generating teaching strategy (Rosenshine et al., 1996). The strategy of *guided co-construction* could be a 'third way' to resolve this dichotomy (Mercer, 1995; Van Oers, 2007; Hardman, 2008). In such an approach the role of the teacher is crucial to connect the practical problems to codified disciplinary knowledge.

We conceive of models '... as any material, materialised (for example a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's action ...' (Van Oers, 1988, p.127). The models function as tools in orientation and communication activities. For example, a model may allow the designer to calculate angles in a drawing in advance, so that steel can be sawn correctly in one single process rather than by trial and error. Here the mathematical formula functions as an orientation tool. When the drawing is subsequently used by students to negotiate about the design, it also becomes a tool for communication. Hence, orientation and communication are both model functions, with the model serving both at the same time. Professional designers in the vocational discipline use models and drawings as thinking tools to generate ideas and to communicate proposals (MacDonald & Gustafson, 2004). When students learn to use models in the same way as professionals the models serve this dual function of orientation and communication.

We needed to look at the classroom micro level in order to find the key determinants that might lead to a deeper understanding of codified knowledge and modelling in the school workshops. For this purpose we used the data of the latest experimental intervention to conduct a qualitative analysis. We aimed, first, to find out in general the precise ways in which designs were implemented at every school. Our next goal was to establish how the modelling developed microgenetically within a process of tandem tricycle construction, and whether it was effective in joining experience and general knowledge, as codified in the general curriculum. The following two questions arose in the process:

1. What was the actual teaching/learning practice in the schools and how did the schools differ, especially in the way the models functioned as tools in the design process?
2. Was the teaching/learning practice aimed at designing and understanding related to the disciplines, both academic and vocational?

Models as tools in the practical design process

In design education, drawings and models often only serve to plan or represent the product to be constructed. By contrast, in professional design processes models and drawings also function as thinking tools to generate ideas and to communicate proposals (MacDonald & Gustafson, 2004). This is in line with our view that models are tools for orientation and communication. We follow Tuomi-Gröhn and Engeström (2003) who state that models can be used, first, to reflect on past processes and subsequently to negotiate a possible direction for their future activity. For example, in vocational education a draft model of a tricycle is a reflection of student efforts to design a product that is to be constructed. It enables the makers to use the model to show where their design process had taken them up to the point of examination and to discuss or explain their solutions to others. Moreover, the model functions as a plan for future action: it *is* the construction plan.

In our view, it is precisely this dual function of models that could bridge the gulf between practical problem-solving and the codified knowledge present in the curriculum. In the case of designing a tandem tricycle, for example, student construction plans can function as models that represent both the state of the design process and the students' orientation on their future activities. Such a plan could, for instance, constitute a reference to the desired length of components, or a tool to anticipate practical problems, for example, the correct order of construction. At the same time, in order to appreciate the applicability of the model, students need to have an understanding of the principles behind the model. They need, in other words, a *disciplined perception* (Stevens & Hall, 1998). Disciplined implies two things: the students have practised, trained and acquired the way practitioners in the field use the models, and the disciplinary concepts, strategies, rules and principles have been understood; in the case of vocational education the disciplines being both vocational (involving domain knowledge and skills) and academic (involving the general curriculum). When students draw models on the basis of rules on how to depict various views of their design, they require a mathematical understanding of ratios, scales and so on. Moreover, in order to develop a strategy in the disciplinary practice of designing models, students need to know how to calculate angles and distances, in ways other than just guessing or drawing to scale.

Drawing a construction model as a means to construct a tricycle is not a goal in itself during the design and construction process. 'The assumption … is that artefacts take on mathematical meaning only in activity, as individuals organize them as means to accomplish particular mathematical goals' (Saxe, 2002, p.

290). Hence modelling should not become a detached subtask to be finished before students are allowed to proceed to construction. Only when modelling is integrated as a functional stragegy in the complete design process, from draft to finished product, can its role and function be truly understood.

These processes of collaboration and negotiation to develop a disciplined perception and a deeper understanding are neither unguided nor minimally guided processes. The teaching strategy is better described as *guided co-construction*. Guiding in a co-constructive way means helping students to collaboratively reconstruct models and subject matter knowledge through an ongoing and reciprocal discursive process, focused on the solution of task-related problems. It is the teacher's role to ' … maintain connections between the curriculum-based goals of activity and a learner's existing knowledge, capabilities and motivations' (Mercer, 2002, p. 143). Research has shown that the instructional strategy of guided co-construction may lead to better understanding of mathematics and modelling than a strategy based on simply providing ready made models as solutions to problems (Doorman, 2005; Terwel et al., 2009; Van Dijk et al., 2003). Mercer (2002) gives the following summary of the characteristics of teachers who were successful in supporting pupils in their development of mathematical problem solving and reading comprehension. Such teachers use questions 'not just to test knowledge, but also to guide the development' (Mercer, 2002, p. 144). They also taught more than just subject content. They helped students understand the problem-solving strategies and make sense of their experiences. Finally, 'they treated learning as a social, communicative process' (Mercer, 2002, p.144). All of these characteristics are elements of what we call guided co-construction. In contrast to a 'providing' form of teaching in which knowledge, concepts and models are presented as ready made solutions, guided co-construction may lead to a better understanding of the process of modelling itself.

The schools in the study were originally assigned to two conditions. In the experimental condition students were guided in a co-constructive way, while in the control condition guidance was more traditional and the models were provided as ready-made solutions. As mentioned earlier, we will not use the conditions as a variable in this article. The schools in each of the conditions adapted the intended design of the curriculum project into somewhat of a unique educational configuration (see below). In the following qualitative analyses all schools will be regarded as separate cases. We looked for ways in which models function in classroom practice and how teachers guided the design process. The main focus of analysis was to find the key determinants of a pedagogy that supports students' modelling and thus the use of models as tools, irrespective of the conditions the students were assigned to.

Method

This multiple case study (Yin ,2006) is part of a design-based research project (Cobb et al., 2003). After the three previous project studies we are currently focusing on classroom micro-processes between teachers and students. The project's overall methodological approach can be placed in the tradition of formative interventions (Engeström, 2009). The concept of mutual appropriation is probably an appropriate concept to understand the dynamics of interventions in (vocational) education (Downing-Wilson et al., in press). Our intended design was adjusted together with the teachers to their local conditions, helping us to understand the school context and helping the team of teachers to understand our aims. The unit of analysis in this study is the subgroup, with teachers present in the classroom.

Quantitative and qualitative data were used from the data gathered. The largest part consisted of video observations and interviews. Together with students' models, drawings and other process data, the data were analysed on the basis of a 'whole to part' approach (Erickson, 2006). The results of a previously analysed study (Van Schaik et al.,submitted a) were used as a starting point and as a result reference for between-school comparisons with regard to the learning outcomes. On the qualitative side, we looked for data that could potentially explain how models were used in practice and how such use might have determined learning outcomes.

Participants and setting

87 students at four schools participated in the study. They worked on the tricycle assignment in subgroups of three, four, or five (all male, mean age 16.06 years). As measured on the pre-tests, the significant differences were on vocabulary, SPM and pre-knowledge. At all schools the teachers were responsible as a team for a larger group of students, which often included the participating students. In total 12 teachers participated. The students worked most of the time in a workshop setting, where computers and technical equipment were available. Some schools used a separate classroom for instruction and/or computer designing (see below). As already mentioned, the four schools were initially divided into two conditions according to their daily teaching and learning practice. Since the way in which the school adapted the intended curriculum design was part of our analyses, detailed descriptions on how the intervention was enacted are reported in the results section.

Schools

School 1: Peter Willems College

This school had 33 students in 11 groups of three working on the project. Students worked in a large central workplace area with a computer room in the middle and two classrooms on the side, where they went for theoretical instruction. Sometimes the computers were used for information searching. Most of the time a single senior teacher guided and graded the students. Other teachers and classroom assistants helped students with practical problems.

School 2: Technical College Oldenhave

At School 2 four groups of four students out of a class of 24 chose to work on the assignment (two other groups were working on other authentic assignments). Students worked in two spaces: one, their 'own', with computers and various forms of technical equipment, and one for the metal work (welding). A team of four teachers, subject matter as well as practice teachers, guided the students.

School 3: Prince of Orange College

At School 3 five groups of four or five, 23 students in all, worked on the assignment. Students worked in a large open workplace with technical equipment and computers available. The subject classes were held in a different part of the school building. The workshop space was one of the corners of a very large 'practice square' with all vocations having their own corner and a central teacher's office in the middle. Computers were available, as well two smaller instruction rooms.

School 4: Orthen Technical School

This school had 15 students working in five groups of three. The workshop space was large and had recently been refurbished. Computers and a separate instruction space were available. Students were guided by both two practical teachers and one teacher who taught prototype lessons. The latter was also a practical welding teacher for the project students. The teacher in question had formerly been a teacher of mathematics and physics. Computers with 2D-CAD software were used for the drawings.

Materials

Assignment

For the student the assignment was the following: *Design and construct a prototype* *of a tandem tricycle for children aged 4-7 in such a way that the children have to cooperate.*

The assignment was placed in the context of a competition among peer students. One of the requirements was the production of a model of the final product as it was actually was constructed. This could be the construction plan as continuously developed, or a 'reverse engineered' model.

The students had to design and construct the tandem tricycle in a ten-week period, during which they worked at least two hours a day in the workshop setting and in open classrooms where computers were available. In both spaces teachers were available for questions and guidance. The design process was reflected on during workshop hours or in lessons or sessions separate from the workshop and the construction process (the prototype lessons). During workshop practice mainly practical problems were encountered, which were most of the time directly solved or redirected to separate lessons. During the latter periods teachers offered guidance in problem solving, using the students' own designs as well as the relevant subject matter in science and mathematics. Models were used either in a providing way or in a co-constructive way; respectively supporting students with ready made models as solution to problems, or guiding them in constructing their own models. For the students the process started with an introduction by the researchers explaining the purpose of the assignment, namely the construction of a prototype to win a competition. During the following first week the students started designing (see figure 6.1 for an example) and moved on to construction in the weeks following. The competition ended in the first instance with the selection of the two best prototypes at each school, followed by a final adjudication with a jury deciding on the winning construction. (figure 6.2).

Guiding instrument for the teachers

A teacher manual was developed which consisted of explanatory notes to the assignment and the possible problems that students might encounter. The manual differed according to the way students in the two conditions had to be guided. For the experimental condition a template for ad hoc lessons and instruction was designed in the manual, and possible content for those prototype lessons was explained. The manual for the control condition consisted of an actual lesson plan.

In both conditions the schools decided when to start and end the project, within a range in line with their annual planning. Students worked on the assignment at least two hours a day during a 9-11 week period.

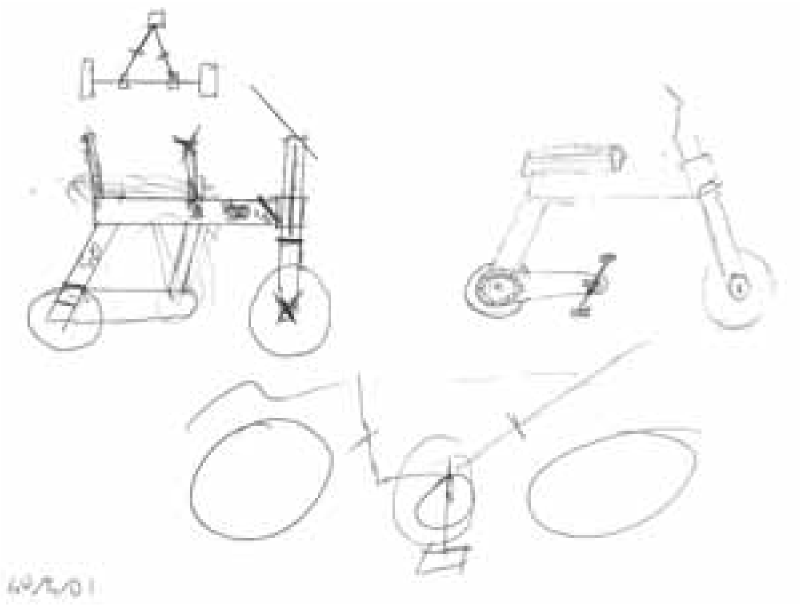

Figure 6.1: first sketch of tricycle of School 1 about here

Figure 6.2: picture of winning tricycle about here

Instruments and procedures

The main source of data for the present analyses were the video data consisting of classroom observations and interviews. Video was collected using a three camera approach, with two fixed cameras recording opposite angles of the whole classroom and one hand-held camera recording the interactions and activities from closer by (see Van Schaik, 2009). The video data were loaded into computer software (Noldus, 2009) and the video streams from each camera were viewed simultaneously.

In addition, data was collected during the intervention in pre- and posttests. The pre-tests included a pre-knowledge and modelling test, a vocabulary test and a test measuring students' mathematical insight and general factor of intelligence (SPM). The posttest consistet of a knowledge and modelling test similar to the pretest.

Analyses

The main focus of the present analysis was to find the key determinants of a pedagogy that supports students' modelling and thus the use of models as tools. We mainly used the observational and interview data. All products, drawings, models and other artefacts were considered in the context in which they appeared. The models that appeared in the observations were classified according to three categories, initial sketches, elaborated and refining drawings, and final and presentation drawings. According to MacDonalds and Gustafson (2004) these are the types of drawings professionals use in their design process. Table 6.1 shows the categories and the clues by which they were established. We used the clues and categories for the models we found in the observations.

We took project week 6 as the starting point for school observation analyses. This was the week in which we expected, on the basis of previous studies, that the students were at a stage between designing and construction. At that point the designs and drawings were in a final state, and could have become tools in the construction process as a means to accomplish the collective goal of tricycle construction. From previous studies we knew that by that time students are at the point where practical design problems occur, for example, when tricycle parts cannot be constructed as planned. Solutions were often purely pragmatic and based, for example, on availability of materials. Sometimes the original construction model had been discarded. This was anticipated in the present study by including one demand in the assignment to the effect that a final drawing had to be of the product 'as constructed' or 'reverse-engineered'.

Project week six was observed at all schools. The video data of those observa-

Table 6.1 Categories and clues for drawings (from MacDonalds & Gustafson, 2004)

Category 1: Initial sketches

Clues

- A sketch is made at the beginning of a project
- The sketch indicates the pupil's initial thoughts/key ideas about the project.
- The sketch is exploratory and conceptual rather than representational.
- The sketch is made quickly and spontaneously.
- The sketch includes images and words.

Category 2: Elaborate and refining drawings

Clues

- A series of freehand and hard-line drawings are made during the project.
- The drawings are shared with other members of the design team.
- The drawings transform the ideas expressed in the initial sketch.
- The drawings elaborate, refine, expand, and develop the pupil's initial ideas.
- The drawings show increasing accuracy and detail, including dimensionally.

Category 3: Final and presentation drawings

Clues

- The drawing is made at the end of the project.
- The drawing is a recognizable representation of the finished product.
- The drawing can be used by those outside the design process as a guide to making.
- The drawing is hard-line, finished, precise, and detailed.
- The drawing is labeled and measured.

Figure 6.3 Tandem tricycle with two front wheels from students in School 1

tions was reviewed and content-coded. Of those video data we labelled the interactions on model construction, preferably interactions with a teacher present. An interaction was labelled when the participants were dealing with a drawing or a model. That is, only when a model or drawing was mentioned, referred to, edited, or looked at for at least five seconds was it scored. If no interaction was found, we checked for its equivalent in earlier observations. Table 6.2 shows the labelled interactions in the models column. Next, by analysing the interviews with the students, we examined how the overall process had developed and whether the week six observation was typical. Finally, the remaining observational data were reviewed to confirm whether the selected interaction was typical or whether it contained critical incidents that might disconfirm typicality. The typical interaction and, if necessary, the critical incident(s) were used in the within-case and across-case analyses next to the subsequently categorised models. For typical interactions the teacher's role was compared to Mercer's characteristics (2002). The students final presentations were incorporated into the experimental condition analyses. Table 6.2 shows an overview of observational video data and interactions on models.

Results

In the qualitative school analyses we discuss whether and how the student drawings and models function as tools during the design and construction processes. In the across-school comparison we compare the qualitative results with the quantitative results from the previous study.

For every school we describe how the intervention was enacted in general (within-school enactment). That is, how designing, constructing and, with regard to the control schools, the prototype lessons were taught. Next, the role of models and teacher guidance is discussed in the within-school enactment. Sample interactions on the role of models and teacher guidance will be described. The overall pattern of each school's enactment is summarised first. In the across-school comparison we discuss how this desciption relates to the learning outcomes, the models and the students' tricycle drawings.

Within-school enactment

School 1.

Overall Pattern: *Teachers in the practice workspace helped the students with practical problems, without explicitly referring to mathematics, science or other codified knowledge.*

Table 6.2 Overview of video data from observations over time and the interactions over models

	School 1			School 2			School 3			School 4		
	Type	duration	models	Type	duration	models	Type	duration	models	Type	duration	models
Week 1												
Week 2												
Week 3	Practice	02:46:17	10	Practice	01:09:09	4	Practice P-lesson	00:47:00 00:32:30	1 0			
Week 4										Practice (drawing)	01:08:13	6
Week 5												
Week 6	Practice	01:09:15	2	Practice	01:53:05	3	Practice	01:03:52	0	Practice	01:46:46	7
Week 7										Practice P-lesson	00:57:07 00:31:21	5 1
Week 8												
Week 9							Practice	00:51:27	2			
Week 10				Practice	01:25:48	3				Practice	02:13:39	0
Week 11	Presentations(10)	00:49:00	2									
Later				Presentations(3)	00:52:05	3						
Total		04:44:32	14		05:20:07	13		03:14:49	3		06:37:06	19

Note: At all schools we observed at least two practice lessons. At school 1 and 2 we observed also the school presentations and at 3 and 4 we also a prototype lesson (p-lesson)

The school did not follow the prototype lesson plan. All the subgroups had to create a wire model of their tandem tricycle made to scale, as well as a drawing and a written plan before proceeding. Drawings were mostly made by hand. Subject matter teachers were sometimes present in the workspace, but did not integrate the practical assignment into their lessons. Teachers assisted the students most of the time with practical issues of the design, stimulating the students to proceed and collaborate; for example how to propel the tricycle, which materials to use, etc. All subgroups had to present their products and processes to their peers and teachers.

In the week six observation analysis two instances of interactions onr models were found. Both were parts of a design issue that developed for more than half of the lesson. A teacher helped a subgroup with finding the right way to create pedals from pieces of steel. The group-constructed tricycle had two front wheels and one rear wheel (see figure 6.3), which was an exceptional design (only two were found among the more than 25 tricycles constructed in all).

The pedals are meant to propel the front wheels directly by using a bent axle. The teacher drew a model for the part that could connect the axle to the frame. There is no reference to student drawings.

Excerpt 1.1

Teacher	[Whilst drawing]
	The fixed part will be connected like this, right?
	Then you'll have to make a little block for the axle to go through.
	You need to connect it with two bolts
	You see?
	You can then put the axle in and move it around.

Later with the students and teacher by the frame:

Teacher:	You see what I mean?
	It can be welded onto this and the axle can run through it.

It is apparent from this interaction that the teacher is only explaining to the students how to proceed. The students' own models and drawings are not mentioned, nor are the students encouraged to draw themselves.

In the other interaction on a model a teacher helps a student to adjust a lathe. The teacher helps the student to first draw the part he is constructing. From the interaction it is not clear what the relation with the tricycle project is, nor was it possible to trace that relation to previous interactions.

The models present in the interaction analysed above were drawn by the teachers. Other models (for example those made by student in week three) were drawn by hand and functioned as draft designs. No subgroup created a reverse-engineered model.

Only two interactions on models were found in week six. However, week three produced 10 (out of a total of 13 interactions over all observations, see Table 2). From that week's observation we learned that the students had to finish their drawings and plans in week three to be allowed to continue with construction. From several interactions between teachers and students it was clear that the drawings required dimensions, scales and views from three angles.. As one teacher said: 'Draw the dimensions, …, that's what I need. Then you are finished with the drawing'. The only reference to mathematics was heard during this week:

Excerpt 1.2

Teacher [Standing at a work bench, whilst drawing and pointing to a scale model for the student]
… if this is 10 cm. larger, it will be a little more than 10 cm. larger, according to Pythagoras, but never mind that.
…
Teacher: You see that?
Student Yes, about there?
Teacher Then you can start with [constructing] the frame.
Student Only that one then, then we can start with the frame. Cool.

The reference to Pythagoras does not amount to anything more than mentioning the existence of the rule. The dialogue continues on how to get the drawing fixed in order to proceed with the construction.

Overall, at School 1 models needed to be elaborated and moderately refined before students could proceed with the actual construction of the tandem tricycle. Once they were into the construction process the models disappeared (after week three) and only the teacher used drawings to help students with the practical issues. The drawings referred to in the interactions were therefore either initial sketches or elaborated drawings.

During peer presentations, students briefly reflected on their processes, while showing pictures and the final product. Only two of the ten groups showed their design drawings, others only mentioned them briefly, if at all. Hardly any questions were raised during the presentations.

Two pairs of students were interviewed. In the interviews the students explained that they sometimes worked on similar projects. The difference with the regular projects was that regular projects come from books and sheets and are short-term. In excerpt 1.3 one student explains the difference between regular assignments and the tricycle assignment.

Excerpt 1.3

Student The [tricycle] assignment is more fun. You are working on a product.
When you are working only on electricity, you are reluctant when you fail over and over again.
[with the tricycle assignment] you can't do anything wrong.
…
You can choose how and what to construct.

One student pair said that drawing took up most of the time, because their first drawing had been rejected by the teacher. The drawing was done by hand and student only received assistance from practice teachers.

In summary, the students were used to working in subgroups on projects such as the tricycle assignment at School 1, although they usually worked on smaller individual assignments. Neither the initial and elaborated student models nor the scale models or design drawings were in evidence any longer after the students were allowed to start constructing. Teachers in the practice workspace helped the students with practical problems without explicitly referring to mathematics, science or any other codified knowledge.

School 2.

Overall pattern: *The drawings and models created by the students develop continuously from initial sketches to final drawings, and are used by the students themselves as well as by the teachers as a tool on which to reflect.*

The students at this school are in a combined stream called 'Comtech', which means that they are used to combining design, commercial insight and technical-practical assignments. All teachers in the team responsible for the group of students, regularly visited the Comtech classroom. During the project no special lessons were taught to the group as a whole. Some students receive specific skill training, or ad hoc instruction. Students used subject matter classes for their 'theoretical' problems. The content of the prototype lessons was taught ad hoc. Students used computers with 2D and 3D Computer Aided Design (CAD) software for their drawings. The project ended with a peer presentation, in which the groups presented themselves as small companies, including production costs, price, processes and product marketing in their presentation.

In week six of their project models and drawings were still lying around in the classroom. All together we counted three interactions on the models involved. In one interaction, a student explains to his group how they should proceed with welding. Another subgroup first discusses construction issues behind the computer screen, with a paper drawing on the desk. Next, the group splits up and three of the members go to the metal classrooms, where they continue their construction. The student responsible for the drawing follows them later to bring the drawing. At the end of the lesson he draws on a piece of wood, explaining to the researcher that he is making a drawing so as to determine the angles for the pieces of steel that have to be sawn. He is using wood because the other students need the paper version of the drawing for their tasks. When the teacher suggests that he could calculate rather than measure the angles the student asks the teacher for help (see excerpt 2.1), in the following exchange:

Excerpt 2.1

Teacher	I should not have to explain this You have to go to the mathematics teacher for that
Student	He is not available
Teacher	Why don't you do it in AutoCAD
Student	AutoCAD does not work, otherwise I would have done it already.
	Student walks out of the classroom and comes back. He is still busy measuring the angle of the pieces to be sawn.
Student	Sir, I measured the angle and it was ..[inaudible]
Teacher	That's what I thought, because it was 60/30/30 [pointing at the angles of three of the complementary corners that make up the square]
Student	Right, then you should have said so
Teacher	Certainly not
	The teacher takes the measuring tool from the table with the pieces of steel on it
Teacher	When viewed from this angle, I see 60/30/30
Student	Right
Teacher	No, this is what you have to learn to see.
	The teacher goes on explaining tricks on how to see, and guess the angle.

In the other observations students were busy creating AUTOCAD or 3D models of their designs. Teachers assisted them and helped determine the expected tricycle dimensions or calculate proportions and scale. In the last observation before the presentations, three elaborated models featured in interactions. The presentation models in the stundent presentations could be categorised as final and presentation drawings.

During the presentations all four groups presented themselves as small tricycle production companies, with logos, names and locations. They reflected on their process starting by showing their final drawing on the projection screen (an example is shown in figure 6.4), which was also the case for subgroups that did not construct a tricycle. Each group explained the difference between drawing and final product and the reasons for those differences. One student tried to make clear to his peers how the 3D modelling software he had used (Solidworks, 2010) could help in getting a better idea of what the final product would look like, as opposed to the 2D AutoCAD version (Autodesk, 2010). In addition, all groups presented calculations of the actual costs and proposed product prices.

The subsequent interview with two students confirmed that is common for students to go to the subject matter teacher for the more theoretical problems. In addition, they are always supposed to have a final drawing of the product as actually constructed. They are used to carrying out projects for clients, but the time for such projects is usually shorter. In connection with their drawing practice the interviewees said that they first made a sketch of the product and, depending on the teacher's approval, proceeded by creating a construction model in AutoCAD. At that point problems would emerge.

Excerpt 2.2

Student	This time the dimensions were a problem. We only saw that when the seats were being constructed. We corrected that in the drawing.

Evidently, the drawing does not disappear during the process. It actually develops while the design is being adjusted during construction. The interview with one of the teachers confirmed that the drawing should reflect all construction changes. The teacher also mentioned that the reason why it is hard to integrate theory into practice is students' enthusiasm for practical construction. He described the ideal process which his team aims towards with the students:

Excerpt 2.3

Teacher	[A student] shows his problem to the mathematics teacher, comes up with a solution, and returns [to the Comtech classroom] …

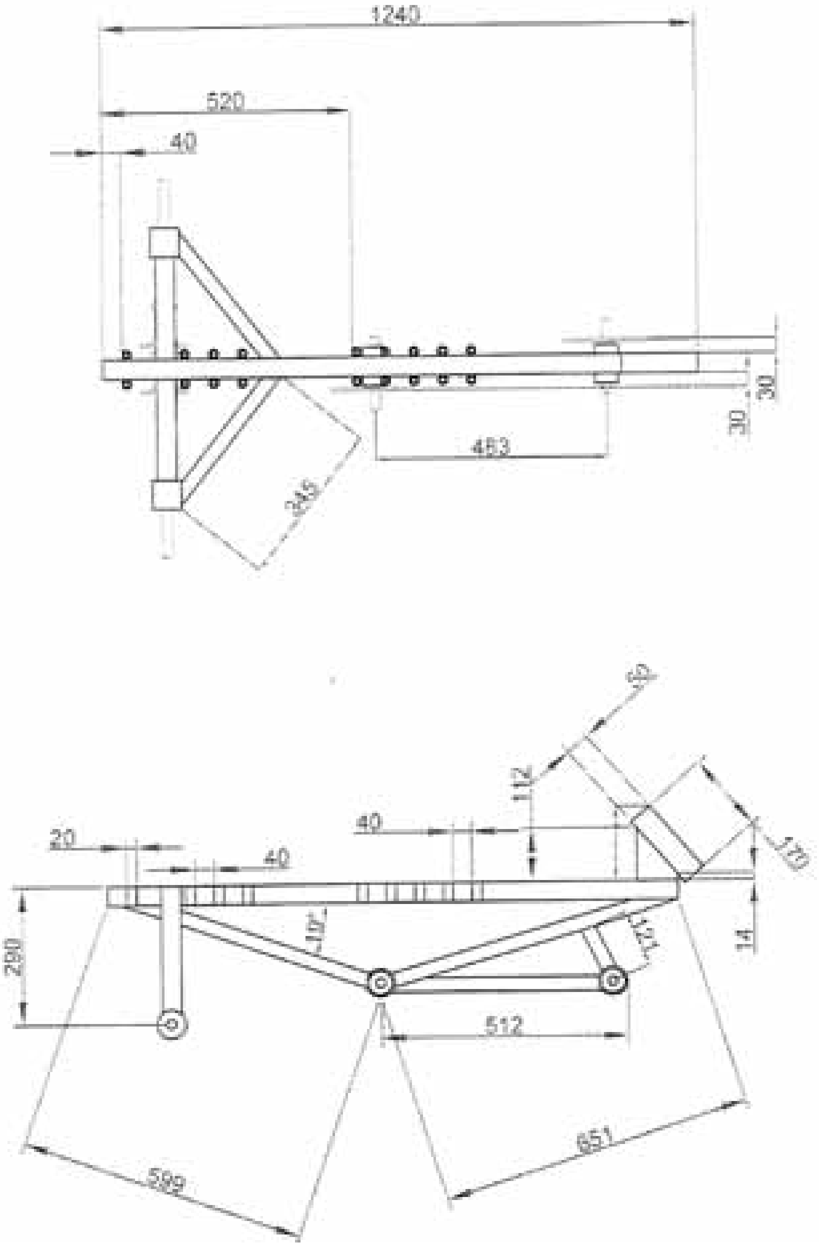

Figure 6.4 Final drawing by School 2 students

That happened with all the groups. More often for some groups than others, though.

School 2 shows that the students work as small production companies for real clients. They design, calculate costs, construct and present as a team guided by several teachers. The drawings and models created by the students develop continuously from initial sketches to final drawings and are used by the students themselves as well as by the teachers as tools on which to reflect.

School 3.

Overall Pattern: *Hardly any relations to curriculum subjects were mentioned. The prototype lesson was an introduction to the practical problems of tricycle construction and only internet pictures or the initial computer drawing were used as reference.*

At School 3 only one practice teacher was responsible for the group and one other teacher assisted in the workshops (the latter was later replaced by a colleague). One subgroup used the computer to draw their reverse-engineered model. One of five possible prototype lessons was taught by a physics teacher, with practical issues the dominant topics for discussion.

In week six no drawings were found in the observation. In week three drawings were still lying around, and only one interaction was found that referred to models or drawings. Week nine found students drawing on the computer. It appeared that they were reverse- engineering their tricycle. Those drawings were made in the software programme 'Paint' rather than CAD. To enable possible further analysis we turned to the relevant week three interactions.

In week three a student comes to the teacher and asks an inaudible question. He holds a piece paper in his hand with a picture of a bicycle on it, presumably from the internet. The teacher tries to explain what the student's plan, which includes the possibility of having two children steer the tricycle, means for the construction design.

Excerpt 3.1

Teacher	So, if you want that, you'll have to connect the handle bars so that they are connected and both turn when one of the kids is steering.
Student	Really?
	[They walk to a metal model of a crane]
Teacher	As you can see, when the handle bars are here and here, the complete construction moves and the bicycle turns.

The example above is typical of the way students in the workshop were guided mainly in their practical constructions. Practical tips and solutions were provided and skills were demonstrated. As already mentioned, hardly any interactions on models were found, neither in the other observations nor in the prototype lesson. Only in week nine were students found behind the computer reverse-engineering their construction drawings. At that stage drawings were still initial sketches.

In an interview with two students during the project, they first pointed out that the difference between the tricycle assignment and the usual assignments was the time available. Normally an assignment took two to three weeks. They also confirmed our observations that no assistance was provided by mathematics or physics teachers. The only help offered was in the workshop during practice hours.

In the interview the teacher confirmed that only a few subgroups created final drawings. He stopped the practice, because he thought it was not 'moving in the right direction'. With regard to student learning he did not think mathematical understanding had improved during the project.

Excerpt 3.2

Teacher	Focusing more attention on mathematics and physics by means of the project did not work out. Although there was some drawing done in AutoCAD … the drawings were not usable … without dimensions and so on. Those are between their [students'] ears.

At this school, especially during the construction stage, we did not find any examples of the explicit use of concepts, models, mathematics or physics. There was hardly any connection with theory as expressed in curriculum subjects. The prototype lesson could be characterised as an introduction to the practical problems of tricycle construction and the only drawings used as reference were an internet and the initial computer sketch.

School 4.

Overall pattern: *By drawing and questioning, the teacher relates the practical issue of construction to the theoretical concepts of transmission, speed and ratio, as well as to other practical examples.*

In comparison to the other schools the students appeared to spend more time on designing. In project week seven they were still found behind computers trying to find the optimal transmission or wheels. Prototype lessons (three out of five) were taught separately to the whole group. The teacher at this school took on a role different from his usual one as a welding teacher. Since his background was in mathematics and science he took the lead in the project. He taught three of the five advised prototype lessons and guided the students during the construction together with one other teacher.

At school 4 we found seven interactions on drawings or models in week six. Many of those were rather short, while the drawings were examined without any discussion. What we would like to discuss here is an interaction on a drawing of which we know how it came into existence through the discussion between the subgroup members recorded in the observation of week four. In that week the subgroup was deeply engaged in a discussion on whether or not they would construct a tandem that could be transformed into two separate bicycles if desired. The problem was how the second bicycle could be steered separately while also having a fixed set of handlebars when connected as a tandem. When this argument was solved, it was decided that the group would construct a detachable tandem (see figure 6.5), which was exceptional since no other group had designed a tricycle of that type. As a result two practically identical bicycles needed to be consructed. The week six interaction is about this particular design (see figure 6.6).

Excerpt 4.1

Teacher	What is this length [pointing to the drawing]
	400?
	40 cm.
	And this one? Have you switched that off [a function in the CAD software]
	Or, you could make this 45 too and this 55
	…
	[students bend the tube and go back to the drawing to check how to saw off tube ends]
Teacher	Which part should be 40? Take your drawing.
	Here you put 40, but is that 40 on the top or,...
Student	That's on the top.

The interaction continues on how to saw off tube parts.

The teacher uses the drawing to help the students with their problem of bending and sawing the frame tubes. He refers to the drawing and not only tries to find out what the students' plans are, but also notes that the drawing is not clear to him. In other words, he uses the drawing and reflects on it as a tool for communication.

Figure 6.5 Connection between bicycles of a two-part detachable tandem at School 4

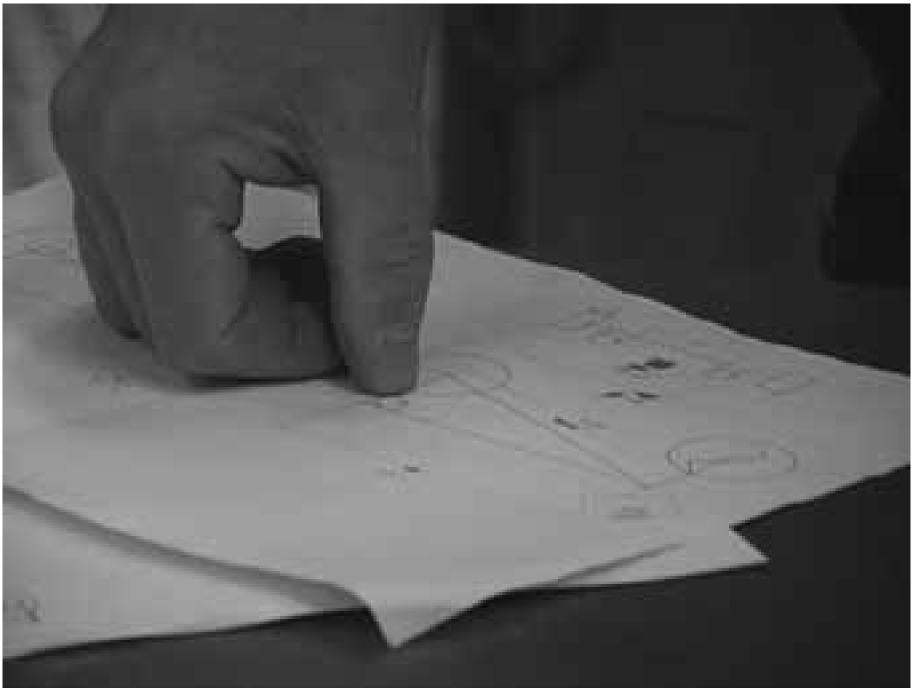

Figure 6.6 Elaborated drawing by students at School 4 to which the teacher refers

In the observed prototype lesson the teacher explores the transmission problem with the students. By drawing a model of a transmission on the blackboard he relates the practical issue of construction to the more theoretical concepts of transmission, speed and ratio. By asking the students questions he tries to make them think of possible gearwheel combinations and their consequences. He follows that up with other examples such as the number of revolutions on a lathe.

Excerpt 4.2

Teacher	Do I need a small [gearwheel] in front and large one at the rear? Or the other way around?
	A student responds
Teacher	Say small in front, large at the rear, then what happens?
	…
	Let's put some figures on it
	…
	Now, what is the number of revolutions for the front wheel per minute?
	How fast will the tricycle move?
	First I need a calculation, a formula.
	…
	[Students respond and arrive at the point where they need to know the circumference of the wheel]
	That's maths: how do I calculate the circumference of a circle?
	[The instruction continues with the speed of the tricycle and the number of lathe revolutions]

Eight drawings were found in all the observations, three of which three initial sketches in week four, three were elaborated and refined drawings in week six and two were other drawings (for instance one on the internet as an example or a short online game). No final or presentation drawings were found. However, the models did not actually disappear after they were created. They were still used in week seven during construction.

What stood out in the interviews with the students was how different the tricycle assignment was from their normal practice. In two interviews, each with two students, it was noted that the students usually work for themselves and have drawings provided. Teachers of mathematics or other general subjects are never present in the workshop. One student explained what he had learned from working with dimensions and ratios during the prototype lesson by saying: '… now I understand it better, because I can work with it more'.

The teacher confirmed the students' statements. He said that the only theory students usually get in practice is reading construction drawings. On the tricycle assignment he thought the students learned mathematics and physics, "because they realise its useful."

At School 4 the elaborated drawings remained present during the construction stage of the project, with teachers referring to them when they helped students with practical problems, such as bending a tube to the correct angle. The observed prototype lesson focused explicitly on the mathematics and physics concepts behind the transmission of a tandem, though the teacher provided the models in a readymade fashion. Working in groups and designing themselves were new activities for the students.

Across-school comparison

In the across-school comparison we are interested in how the overall process at all schools can be characterised and to what extent schools differ in their enactments. We eventually relate this to the learning outcomes as measured by the tests.

First, week six observations confirm the experience from earlier studies to the effect that at that stage in the process at three of the four schools the students are in fact in between designing and construction. The video data show that the frames of most tricycles are finished and students are connecting the other parts to it. At Schools 1 and 3 wheels are already connected and students are playing with the tricycles. Except for one school (School 3), drawings and models are still present in the workplace. At Schools 2 and 4 the models are explicitly referred to and used as tools for communication and orientation. At School 2 this reference is used not only to solve the practical problem but also as an example to refer to the academic discipline of mathematics: how to calculate and estimate angles (see excerpt 2.1). The orientation goes beyond the actual construction towards the formulation of a strategy.

Secondly, it seems that the construction is now the main object of the students' activities, from week six onwards. All interactions are about what to do how in construction. The teachers mostly have to help with practical problems, such as where to find tools or how to adjust the machines. At School 1 this is already the case in week three, when construction drawings and plans have to be finished.

Table 6.3 shows that at School 2 all subgroups (four) had final presentation drawings. Although some students at School 1 use their drawings during presentation, they do not reflect on the drawing itself or use it as a tool to explain their process. At no other school were final drawings found. At School 3 only initial sketches were observed. Apparently, the design process continued until the end of the project only at School 2, while drawings were also used as tools for communication.

In characterising the four schools we observe that two schools stand out. At School 2 the drawings and models are not only used and refined until the end but they are also used to explicitly refer to mathematics. In addition, during the discussion on the place of mathematics in drawings, the teacher revealed something of his approach to teaching in his student guidance (see Excerpt 2.1). At School 4 the drawings remain present during construction and are used by teachers and students as tools to communicate on practical problems. The teacher used models to explain mathematics and physics related to the tricycle assignment during the prototype lesson. At the two other schools (1 and 3) the models were all but absent or disappeared during the process, and hardly any explicit attention is given to mathematics or scientific concepts.

Since the above analyses are qualitative follow-ups in relation to the same intervention, we are in a position to further articulate these outcomes by means of a brief overview of the test data results. School 2 had the highest scores on the premeasures (Vocabulary, SPM, pre-test). The subsequent analyses showed that, although its mean scores on the School 2 post-test were higher, School 4 had the highest *adjusted* post-test mean. (Van Schaik et al., submitted a). That is, after correction for differences on the premeasures, School 4 scored highest on the ost-test. Compared to the quantitative results the qualitative analyses confirms the slightly, but not significantly, better results of School 2 and 4. At those two schools models were used as tools during the whole process and students scored better on the post-test. In addition, at School 4, where the project differed from the usual school practice, students benefited most (i.e. highest adjusted means on the posttest). At School 2, where usual practice resembled that of the project, students scored relatively well on the pre-test and the posttest. In other words, as compared to the other schools the intervention had already started prior to the pre-test for this school. The differences between pretest and posttest were therefore smaller, as the results of the pretest already incorporated the effect of the intervention.

Conclusion & discussion

In this paper we argue in favour of modelling as a core activity during practiccal classes to improve students' understanding, and to effect an integration between practical work and general curriculum subject matter. Qualitative and quantitative data from interventions at four schools were analysed in order to find key

Table 6.3 Drawings in observations during the process

Note: the amount of models may be less than the amount of interactions over models, since one model can appear in more than one interaction.

	School 1	School 2	School 3	School 4
n	33	16	23	15
Total drawings	12	12	2	8
Initial drawings	5	0	1	3
Elaborate drawings	3	7	0	3
Final drawings	1	4	0	0
Other	3	1	1	2

determinants of a pedagogy that supports students' modelling and thus the use of models as tools.

In general, we wanted to know how precisely the proposed design was enacted at each school. We then aimed to establish how the activity of modelling developed in a practical environment, involving the process of constructing a tandem tricycle. In addition we sought to establish whether modelling was effective in joining practical experience to theory as codified in the general curriculum. In view of the above aims, our two research questions were the following:

1. What was the actual teaching/learning practice in the schools and how did the schools differ, especially in the way the models functioned as tools in the design process?
2. Was the teaching/learning practice aimed at designing and understanding related to the disciplines, both academic and vocational?

From analyses of the within-school enactment and from across-school comparisons it is clear that two schools stand out in the way models are used in their practice workshops. Each school could be characterised by a unique, overall interaction pattern. In the present section we will elaborate - and reflect on - these patterns in the light of our theoretical assumptions on modelling. At Schools 2 and 4 the models remained visible and continued to be used until the end of the process, whereas at Schools 1 and 3 the models to all intents and purposes disappeared once the actual construction of the tandem tricycle had begun. The conclusion is that the use of models at Schools 2 and 4 resembles the practice of professional designers more accurately than at Schools 1 and 3 (MacDonald & Gustafson, 2004). Moreover, at Schools 2 and 4 far more interactions on models were found in the observations. Teachers and students used their models as tools for orientation and communication. The first was observed for example when students at School 4 discussed whether or not to design a tandem that could also be dismantled into two separate bicycles (see p.129). At School 2 students communicated by means of models when they tried to find solutions to practical problems, for example in determining the correct angle for sawing off tube ends (e.g. excerpt 2.1). They updated their drawings when the design changed during the construction process. This updating could be viewed as a way to establish their collective memory and use the model as a tool for communication at later moments in time, with themselves or their peers (see Excerpt 2.2). Although interactions on models were also observed at School 1 (not at School 3), the teacher at that school regarded the students' models as tasks to be finished before actual construction could start. Hence, the students' drawings were checked on certain points, after which they were discarded. Teachers only used their own models to help students with practical problems. The answer to our first research question is therefore that at School 2 and 4, as opposed to School 1 and 3, the drawings were actual tools in the design process and remained visible until the end of the project.

With regard to students' understanding of the disciplines, we are led to the conclusion that at School 2 the vocational discipline of (technical) designing was the main goal. Students continued designing and created a final presentation model on which they reflected during a presentation to peers and teachers. At School 4 the academic disciplines of mathematics and physics were given explicit attention during the process, with the teacher teaching the appropriate content during the prototype lessons. In addition, the quantitative data show that School 4 had the highest adjusted means on the post-test which measured the relevant knowledge, whereas School 2 scored highest on all pre- and postmeasures. At the two other schools there were few signs of attention to academic disciplines during workshop practice. The teaching/learning strategies seemed mainly aimed at vocational skills. In sum, the formation of disciplined perception (Stevens & Hall, 1998) was only supported at Schools 2 and 4.

In addition to the support for disciplined perception, the drawing of construction models as a means of constructing a tricycle at Schools 2 and 4 was not merely a goal in itself during the design and construction process. Teachers at both schools explicitly pointed out the function of models to the students. Sometimes models were used to to find solutions to practical problems (e.g. the correct way of bending a tube to the right angle), while at other times the teacher used models to refer to mathematical rules (e.g. calculating or estimating angles in a drawing). We conclude therefore that at those schools modelling was integrated into the overall design process, from draft to finished product. As a result the role and function of modelling was well understood by the students.

The teaching strategy at School 2 resembled best that of guided co-construction. The students collaboratively reconstructed models through an ongoing and reciprocally discursive process, focused on the solution of task-related problems. However the knowledge codified in the subject curriculum was only indirectly referred to. At School 4 on other hand, codified knowledge was taught in a providing way, resembling direct instruction.

Since it is the teacher's role to ' … maintain connections between the curriculum-based goals of activity and a learner's existing knowledge, capabilities and motivations' (Mercer, 2002, p.143), the question remains how codified knowledge is best instilled. Consequently we suggest that discussions about unguided or minimally guided or direct instruction (Kirschner et al., 2006) should be abandoned in favour of finding out what teachers actually do, when, where and how. In our view, then, further research is required to explore teaching/learning strategies that incorporate the practices of schools such as Schools 2 and 4.

The present study explored an intervention at four schools, using both qualitative and quantitative data. A next step could be to conduct a meta-analysis on the data of the entire design-based research project, incorporating data from the first case study plus the two interventions. This would enable a more accurate definition of the optimal teaching/learning strategy, which could subsequently be used in a larger scale follow-up design experiment.

Even on the limited basis of the present data the conclusion is warranted that modelling is potentially capable of enriching practical assignments with theoretical concepts from mathematics and science. Such enrichment is, in turn, capable of creating disciplined perceptions. The two schools which produced the most models observed in interactions were also the ones that showed the highest scores, while the difference between the two schools consisted in the conditions we initially created. We conclude that modelling as a core activity in vocational education could be the key to integrating theory into the workshop.

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.

Nederlandstalige Samenvatting

Samen modellen construeren als 'tools' in de beroepspraktijk
Leren in een kennisrijke omgeving

Iets meer dan de helft van de leerlingen in de klassen drie en vier van het voortgezet onderwijs volgt een VMBO opleiding. Dat staat niet in verhouding tot de mate waarin deze sector voorkomt in wetenschappelijke literatuur. Langzaam maar zeker verschijnen de eerste artikelen en rapportages over onderzoek in het VMBO (zie bijvoorbeeld: Boersma, ten Dam, Monique Volman, & Wardekker, 2009; Koopman, Teune, P., & Beijaard, in press.; Seezink, 2009; Van Schaik, Van Oers, & Terwel, in press; Van de Pol, Monique Volman, & Beishuizen, in press). Dit proefschrift is een volgende toevoeging aan die reeks en beschrijft een onderzoek dat tussen 2006 en 2009 op zeven scholen is uitgevoerd. De hoofdvraag van het gehele onderzoeksproject is: zijn de leeruitkomsten van leerlingen, die deelnemen als ontwerpers in een proces van guided co-construction met peers en experts (leraren), beter dan de leeruitkomsten van leerlingen die leren te werken met kant en klare modellen, aangereikt door de leraar?

Vanaf begin in 1999 was het VMBO bedoeld als een onderwijsinnovatie (Van der Waals, 2009). Van oorsprong was het beroepsonderwijs vooral gericht op vaardigheden. In de tachtiger jaren van de vorige eeuw kwam bij de voorgangers van het VMBO de nadruk meer op theorie te liggen. Geen van beide benaderingen voldeed volledig. De eerstgenoemde praktische benadering hielp de leerlingen niet optimaal zich breed te ontwikkelen. De tweede benadering was vaak te moeilijk en leidde tot betekenisloos mechanisch leren. De laatste jaren zijn in het VMBO de leraren op zoek naar een balans tussen theorie en praktijk. Van der Waals (2009) noemt dit een stille revolutie.

Een belangrijke vernieuwing in het VMBO betreft de ontwikkeling van geïntegreerde leeromgevingen. Praktijkvakken en vaktheorie worden niet langer afzonderlijk aan de orde gesteld. Ook komt het voor dat AVO-vakken zoals wiskunde, Engels en Nederlands geïntegreerd worden in de praktijkopdracht. Leraren en leerlingen worden gezien als (mede-) ontwerpers van geïntegreerde leeromgevingen (vlg. ook Van der Sanden, Streumer, Doornekamp, Hoogenberg, & Teurlings, 2003). De opdracht waaraan de leerlingen in dit onderzoeksproject werkten was het ontwerpen en bouwen van een tandemdriewieler. De opdracht moest kennisrijk zijn en authentiek. Dat wil zeggen dat de leerlingen geïntegreerd theorie en vaardigheden konden leren. Authentiek betekent dat de leerlingen de betekenis van hun handelen inzagen en dat het werken aan de opdracht representatief is voor hun toekomstig mogelijk beroep (Volman, 2006).

In dit praktisch en technisch handelen speelt het 'leren modelleren' een centrale rol. Modellen zijn o.m. schetsen, vaktekeningen, schema's, tabellen, formules etc. Modellen kunnen worden ingezet ten behoeve van de praktische uitvoering, maar ook om technisch en wiskundig te leren denken in alle fasen van het proces.

Theoretisch kader

De gedachte achter het authentiek leren in geïntegreerde leeromgevingen is dat gecodificeerde kennis tegelijk met beroepsvaardigheden geleerd kan worden door te werken aan 'echte' opdrachten. In het VMBO gebeurt dat vooral op de scholen zelf in werkpleksimulaties (Van der Sanden, Streumer, Doornekamp, Hoogenberg, & Teurlings, 2003). Het is echter niet vanzelfsprekend dat door werkplekleren ook gecodificeerde kennis verworven wordt (Nijhof, Nieuwenhuis & Terwel,2006; Tynjälä, 2008). Het onderwijs zou de studenten moeten begeleiden van praktische problemen naar gecodificeerde kennis van de AVO vakken (Guile & Young, 2003; Van der Sanden, Terwel, & Vosniadou, 2000). Daarvoor zouden studenten geholpen zijn met "conceptuele en didactische instrumenten die het mogelijk maken om theoretische kennis te integreren met hun praktische ervaringen" (Tynjälä, 2008, p.145. Guile & Young, 2003, p. 73) noemen zo een werkplek een 'kennisrijke werkplek'. Kennisrijke werkplekken kunnen studenten betrekken in betekenisvolle activiteiten en tegelijk kennisontwikkeling stimuleren (zoals wiskunde bij Kent, Noss, Guile, Hoyles, & Bakker, 2007). Modellen kunnen op die kennisrijke werkplekken functioneren als conceptueel en didactisch instrument.

Modellen als 'tools'

Hoewel er veel definities zijn definiëren wij modellen als Van Oers (1988) "... als elke materiële, gematerialiseerde (bijvoorbeeld grafisch weergegeven) of mentaal voorgestelde constructie, opgebouwd uit identificeerbare elementen en relaties, die de handelingen van een gebruiker op een bepaalde manier structureert ... " (p.127). Deze modellen functioneren als 'tools' voor oriëntatie en communicatie vergelijkbaar met wat Tuomi-Gröhn & Engeström (2003) beschrijven. Een model kan bijvoorbeeld de ontwerper helpen hoeken te berekenen, zodat het staal in één keer goed afgezaagd kan worden, in plaats van door 'trial and error'. De wiskundige formule hiervoor functioneert dan als een tool voor oriëntatie. Als een tekening door studenten gebruikt wordt om het ontwerp te bespreken, dient het als tool voor communicatie. Oriëntatie en communicatie zijn beide functies van een model en een model kan op hetzelfde moment beide functies vervullen.

Guided co-construction

In het VMBO leren leerlingen in zowel 'communities of practice' (Lave & Wenger, 1991) als in 'communities of learners' (Brown & Campione, 1994; Lemke, 2000; Rogoff, Matusov, & White, 1996). Leerlingen worden tegelijk geïntroduceerd in bepaalde sociaal-culturele praktijken (zowel de beroepspraktijk als de wiskundige praktijk) en gedurende het leerproces bewegen ze zich ook in een leergemeenschap. Dat proces kan omschreven worden als 'legitimate peripheral participation' (zie Lave & Wenger, 1991), waarbij er kwalitatieve verandering van activiteiten plaatsvindt die de deelnamemogelijkheden bevordert (Van Oers & Wardekker, 2000).

Modelleren zou een deel van een leerstrategie moeten worden voor het probleemoplossen en leraren moeten dan precies die functie van modellen leren aan studenten. Dat wil zeggen modellen moeten tools worden voor oriëntatie en communicatie, in plaats van alleen maar representaties zonder een relatie met het uiteindelijke doel van het ontwerpen.

Als tools voor communicatie en oriëntatie helpen modellen leerlingen vooruit te denken en te reflecteren op hun eigen proces. De rol van de leraar is dat dan te ondersteunen en hen zo discursief te leiden in hun proces van het (re) construeren van de modellen die beide functies optimaal vervullen voor de voorliggende taak. 'Guided-co-construction' betekent studenten helpen samen modellen en (AVO)kennis te reconstrueren in een voortdurend en reciprook proces, gericht op het oplossen van taakgerelateerde problemen. Het is de rol van de leraar om "... verbindingen te behouden tussen de curriculumdoelen van de activiteiten en de bestaande kennis, vaardigheden en motivatie van de leerlingen" (Mercer, 2002, p. 143). Onderzoek heeft aangetoond dat de strategie van guided co-construction kan leiden tot een beter begrip van wiskunde en modellen dan de 'providing' aanpak: het aanbieden van kant en klare modellen (Doorman, 2005; Terwel, Van Oers, Van Dijk, & Van Eeden, 2009; Van Dijk, Van Oers, & Terwel, 2003).

Methode

Het gehele onderzoek is te typeren als ontwerponderzoek (Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004; The design based research collective, 2003; Shavelson, Phillips, Towne, & Feuer, 2003). In drie fasen is een opdracht voor leerlingen op scholen ingevoerd en bestudeerd. In alle fasen zijn de docenten betrokken geweest bij het aanpassen van de interventie aan hun schoolpraktijk. De benadering van de formatieve interventie sluit daarom aan bij onze aanpak (Engeström, 2007). Tevens was er gedurende het ontwerpproces sprake van wederzijdse erkenning (‘mutual appropriation’) van lerarenteams en onderzoekers (Downing-Wilson, Lecusay, & Cole, in druk). De leraren leerden de bedoelingen en theorie daarachter van de onderzoekers kennen, terwijl de onderzoekers leerden begrijpen wat er wel en niet kon op de scholen en hoe de leraren omgingen met de interventie. In alle fasen van het onderzoek is video gebruikt voor observaties en interviews. De videodata hebben het onderzoek helpen ontwikkelen. Ten eerste door vanuit de video-analyse het onderwijsontwerp kon worden aangepast. Ten tweede omdat ook de methode door middel van de video in beeld kwam en daardoor zowel beter afgestemd als gevalideerd kon worden. Ten derde omdat met terugwerkende kracht in de video de ontwikkeling te zien was van het de theorie: het perspectief, letterlijk en figuurlijk, veranderde in de loop der tijd.

Case study

In een eerste studie is op één school het functioneren van de opdracht voor de leerlingen bestudeerd. Doel was het creëren van een ‘kennisrijke’ leeromgeving (Guile & Young, 2003; Nijhof & Nieuwenhuis, 2008). Het idee achter een kennisrijke leeromgeving is dat daar meer geleerd kan worden dan vaardigheden en gesitueerde kennis door vanuit praktische, ‘echte’ opdrachten tot abstractere en academische kennis en modellen te komen. Een voorbeeld is het leren over het natuurkundige principe van overbrenging vanuit het ontwerpen van een tandem-driewieler.

De patronenanalyse (Terwel, 2005) op basis van de video-observaties leverde drie patronen op: leerlingen worden geacht het denkwerk vooral buiten het praktijklokaal te doen; bij het probleemoplossen worden de modellen kant en klaar aangeboden; de opdracht is motiverend als de opdrachtgever echt ‘klant’ is. De conclusie was daarom dat de opdracht potentieel kennisrijk was en motiverend voor de studenten, omdat het zorgde voor een behoefte aan het leren van nieuwe kennis en vaardigheden. Tegelijk bleek dat die kennis, onder meer in de vorm van modellen, vaak als kant-en-klaar aangeboden werd door de leraar.

Eerste experiment

In de tweede studie is de opdracht uitgewerkt voor twee condities op twee scholen. In de experimentele conditie ontwerpen de leerlingen de modellen die nodig zijn zelf in samenwerking met elkaar en onder begeleiding van de docent. Dit proces van ‘guided co-construction’ helpt leerlingen de modellen beter te begrijpen, omdat ze doelgericht ermee aan de slag zijn (Terwel, 2009). In de controle conditie worden de modellen als kant en klare oplossingen aangeboden. Het bleek dat de twee groepen in traditionele kennis niet verschilden. De leerlingen in de experimentele conditie maakten wel betere eindtekeningen van de driewielers. Uit analyse van de kwalitatieve data bleek dat in de experimentele conditie de modellen inderdaad functioneerden als tools in het ontwerp- en bouwproces, maar dat in de controle conditie de modellen langer zichtbaar bleven in het proces. De conclusie was daarom dat guided-co-constructie met expliciete aandacht voor modellen kan leiden tot verwerven van kennis begrip van modelleren.

Tweede experiment

In de derde studie is het experiment van interventie I verder aangepast en ingevoerd op vier scholen. Belangrijkste aanpassing was het toevoegen van 'prototypelessen'. In die lessen werd leerlingen de gelegenheid geboden om te reflecteren op het proces van ontwerpen en bouwen.

De analyses van dit tweede experiment zijn verdeeld over twee studies. Uit de eerste studie, vooral op basis van kwantitatieve data bleek dat twee scholen, uit elke conditie één, veel beter op de kennistests scoorden. Verdere analyse wees uit dat deze scholen expliciet het functioneren van modellen ook verbinden met de theorievakken. Daarnaast hadden de scholen een kleinere leerling/leraar ratio. In de tweede studie bleek uit kwalitatieve analyses dat op de twee goed scorende scholen er meer modellen van de producten langer zichtbaar bleven in het proces, verder uitgewerkt waren en dat ze nadrukkelijk functioneerden als tools in dat proces. De conclusie was dat op die scholen het ontwerp en constructieproces het meest leek op dat van professionele productontwikkelaars. Als gevolg daarvan werden de leerlingen mogelijk beter geoefend in het benaderen van problemen op een beroepsmatige én academische manier: hun 'disciplined perception' werd beter ontwikkeld.

Conclusie & discussie

De hoofdvraag van het gehele onderzoeksproject was: zijn de leeruitkomsten van leerlingen, die deelnemen als ontwerpers in een proces van guided co-construction met peers en experts (leraren), beter dan de leeruitkomsten van leerlingen die leren te werken met kant en klare modellen, aangereikt door de leraar? Het antwoord daarop is tweeledig. Er kan geconcludeerd worden dat de studenten leren modelleren en dat guided-co-construction nagenoeg dezelfde resultaten oplevert als een 'providing' aanpak. De opdracht van de tandemdriewieler was kennisrijk en de natests van de experimenten bewezen dat er na de interventies geleerd was op het gebied van wiskunde en modellen. Toch denken we dat de strategie van ‘guided co-construction’ leerlingen helpt bij het leren van gecodificeerde kennis en begrip van modelleren. Ten eerste omdat de modellen van de leerlingen in de experimentele conditie van het eerste experiment beter waren. Daar werden de modellen als tools voor communicatie en oriëntatie gebruikt. Ten tweede omdat in het tweede experiment op die scholen die iets beter presteerden, er meer en verder uitgewerkte modellen langer deel van het proces bleven uitmaken. Daar was het voor de leerlingen mogelijk in de praktijklokalen tegelijk kennis en vaardigheden op te doen die zowel betrekking hadden op de beroepspraktijk als op academische vakken als wis- en natuurkunde.

Het VMBO is complex. Niet alleen vanwege het duale van de praktische en algmeenvormende doelen, maar ook vanwege de dynamiek op de scholen. De benadering van de formatieve interventie helpt die dynamiek begrijpen. Met behulp van de videodata hebben we tijdens, maar ook achteraf, zicht kunnen krijgen op ons onderzoeksproces. In de video is met terugwerkende kracht te zien dat er sprake was van wederzijdse erkenning tussen onderzoekers en leraren. Video, in design based onderzoek in het bijzonder, bewijst daarmee dat het een onmisbaar instrument is in onderwijsonderzoek dat zich ook direct richt op ontwikkeling van de praktijk. Gevolg is dat door video-analyse ook duidelijk werd dat er meer kwalitatieve micro-analyses nodig zijn om te weten te komen wat er tijdens het werken aan authentieke opdrachten precies geleerd wordt. Tegelijk heeft het gebruik van video tegelijk ook de methode en het theoretisch kader helpen ontwikkelen.

Na een decennium van onderzoek op het gebied van providing versus co-constructie zijn we met hulp van gedetailleerde video-analyse op een punt aangekomen dat gedefinieerd kan worden als de studie naar het aanreiken van modellen *binnen* een context van guided-co-construction en manieren van het zinvol gebruiken van tools en gecodificeerde kennis tijdens het proces van ontwerpen en bouwen van producten door leerlingen.

Hoe dan ook, leerlingen leren modelleren van authentieke opdrachten. De meeste driewielers zijn voltooid en er is wis- en natuurkunde geleerd. Daarnaast geven de leerlingen in interviews aan de opdracht leuk en uitdagend te vinden. Samen geeft dat aan deze aanpak in het VMBO veelbelovend is.

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Curriculum vitae

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