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## Co-constructing Models as Tools in Vocational Practice

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VRIJE UNIVERSITEIT

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  
ten overstaan van de promotiecommissie  
van de faculteit der Psychologie en Pedagogiek  
op donderdag 2 december 2010 om 15.45 uur  
in de aula van de universiteit,  
De Boelelaan 1105

door

Martijn van Schaik

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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## General introduction 2

### Co-constructing models as tools in vocational practice 3 Learning in a ‘knowledge-rich’ environment 4

Dutch preparatory senior secondary vocational education<sup>1</sup> 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).

---

<sup>1</sup> 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.

1 As an attempt to improve the relevance of the knowledge and the effectiveness  
2 of transfer to the workplace, reforms are taking place in Dutch pre-vocational  
3 schools (De Bruijn, 2004; Guile & Young, 2003; Seezink & Van der Sanden,  
4 2005), as in other countries. One of the proposed reforms envisions the teaching-  
5 learning process as an activity embedded in a simulation of real world practices,  
6 whereby students, guided by teachers, work on products for ‘real’ customers, in  
7 the meantime acquiring new knowledge and skills. The basic assumption behind  
8 this approach is that the learning of codified knowledge and vocational skills  
9 can be integrated into authentic workshop practices. The pedagogical approach  
10 is what Tynjälä labels “integrative pedagogics”, which is more of a principle in-  
11 tegrating theory and practice than a specific teaching method (2008, p. 144).  
12 However, working on a (practical) problem is not enough to motivate students  
13 to learn (Guile & Young, 2003), and participating in real life situations is not  
14 sufficient to develop expertise on a higher level (Tynjälä, 2008). Explicitly taught  
15 knowledge, for example knowledge about modelling or knowledge gained in  
16 mathematics education classes, is not automatically used for problem solving in  
17 a workshop setting, and vice versa. Students simply do not recognise the connec-  
18 tion between theory and practice. This may result in reduced learning outcomes  
19 and lack of motivation on the part of students. The challenge for schools is to  
20 provide assignments that are meaningful for students and realistic with regard to  
21 their future work (Terwel, 2009; Tuomi-Gröhm & Engeström, 2003; Volman,  
22 2006). At the same time, those assignments should also result in highly quali-  
23 fied learning outcomes that enable students to recontextualise their knowledge  
24 and skills acquired in the classroom to the workplace. Teaching should support  
25 students in relating practical problem solving to codified curriculum knowledge  
26 (Guile & Young, 2003; Van der Sanden, Terwel, & Vosniadou, 2000). It follows  
27 therefore that students, when solving real life problems, need to be supported by  
28 “conceptual and pedagogical tools which make it possible for them to integrate  
29 theoretical knowledge with their practical experiences.” (Tynjälä, 2008, p.145).  
30 Real workshop activities could increase the need for specific knowledge and  
31 skills, and subsequently provide opportunities for learning. Following Guile &  
32 Young (2003), such workplaces can be characterised as a “knowledge-rich work-  
33 place” (p.73). They are assumed to engage students in meaningful activities while  
34 at the same time promoting subject matter learning (including mathematics, see  
35 Kent, Noss, Guile, Hoyles, & Bakker, 2007).

36

37

## Models as tools

38

39 In vocational education, students are sometimes involved in such knowledge-

rich workplaces while designing and constructing real products. In the design 1  
process as well as in the actual construction issues arise that need to be solved. To 2  
anticipate possible problems and their solutions models may be used. Although 3  
drawings and models are important in the design of technology and serve both 4  
to communicate and generate ideas, MacDonald & Gustafson (2004) claim that 5  
in classrooms the emphasis is on their mere representational function. Students 6  
have to draw correctly, while their models are only used for teacher diagnostics. If 7  
in these types of environment student drawing were related to orientation in the 8  
problem situation as well as to an exploration of ideas, modelling might turn into 9  
action-cum-learning strategies by which students could gain deeper understand- 10  
ing of problems and their possible solutions. 11

Following Van Oers (1988), a model is defined in this thesis as "... any material, 12  
materialised (for example a graphical display) or mentally pictured construction, 13  
built up from identifiable elements and relations, which structures the user's ac- 14  
tion ..." (p.127). These models function as tools in activities for orientation and 15  
communication, in ways similar as described by Tuomi-Gröhn and Engeström 16  
(2003). For example, a model may allow the designer to calculate angles in a 17  
drawing in advance, for example to correctly saw steel in a single process rather 18  
than by trial and error. Here the mathematical formula functions as an orienta- 19  
tion tool. When the drawing is then used by students to negotiate the design, it 20  
becomes in addition a tool for communication. Hence, orientation and commu- 21  
nication are both functions of a model, and a model can serve both at the same 22  
time. 23

From a sociocultural point of view models have two core functions: orientation 24  
and communication. These functions are not mutually exclusive. Orientation, 25  
according to Galperin, is essentially a psychological action moment. This process 26  
acquires a cultural form which is characteristic for a certain practice, leading what 27  
is usually called 'disciplined perception' (Stevens & Hall, 1998). Models play a 28  
particularly important role in this process: a model is a cultivated tool for orienta- 29  
tion towards future actions (Van Oers, 2006), providing direction to someone's 30  
activities. Orientation includes valuation, produces information, and functions 31  
as a basis for plans and predictions. As tools for communication, models foster 32  
the distribution of individual ideas and meaning across the community. When 33  
students work together, as in our case on the construction of a tricycle, they uti- 34  
lise drawings and ideas to plan and predict the process, and to discuss the final 35  
design. The models provide direction not only to the actual design and the plan- 36  
ning of the activities but also to the coordination of ideas and actions among the 37  
participants. In other words, the models assist in anticipating the outcomes and 38  
meaning distribution in a community (Gal'perin 1969;1979 in Van Oers, 2006). 39

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

12  
13  
14

### Guided co-construction

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

26 Furthermore, empirical analysis has shown that in the accomplishment of ac-  
27 tivities new goals and needs may emerge which drive participants to construct or  
28 adopt new tools (cf. Kozulin, Gindis, Agayev, & Miller, 2003; Saxe & Guberman,  
29 1998). Hence, by participating in communities, students may be compelled to  
30 aim for new goals that encourage them to adopt appropriate new practice-related  
31 tools, including concepts, symbols and models (Gravemeijer, Lehrer, Van Oers,  
32 & Verschaffel, 2002). In guiding the participation process teachers help their  
33 students understand the use and meaning of the concepts, symbols and models  
34 as tools in a range of similar practices. At the same time the teachers themselves  
35 are participants in the same community, as much involved in the co-construction  
36 process as the students. It is important to remember that the teacher is not just  
37 a guide in this process of meaning making, but also a genuine participant (Van  
38 Oers, 2001). For example, the teacher may help students create a construction  
39 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

1 co-construction with an expert (teacher) and peers, show better learning out-  
2 comes than students who learn to work with ready-made models provided by the  
3 teacher?

4 The general working hypothesis for this study is that collaborative learning to  
5 design and use models in vocational education has positive effects on learning  
6 outcomes, as compared to providing ready-made models to the students. The  
7 basic idea underlying the hypothesis is that students will develop knowledge  
8 and skills in modelling along with codified knowledge in mathematics and sci-  
9 ence as a result of constructive involvement and dialogic inquiry under teacher  
10 guidance.

11 The overall research project was split into three interventions: a case study, and  
12 two experiments in a pre-test post-test control group design. These interventions  
13 resulted in four studies (see below). For every study the specific research question  
14 differed. The first questions we addressed in Study 1 (case study) were: (1) What  
15 teaching/learning processes occur in a simulated workplace using the concept of  
16 a knowledge-rich workplace? (2) What is the role of models and modelling in  
17 teaching/learning processes?

18 Next, for the first experiment in Study 2, two conditions were shaped in a pre-  
19 and post-test control group design: a ‘providing’ condition (control group) and  
20 a ‘guided co-constructing’ condition (experimental). The research question ad-  
21 dressed the differences between the conditions and was divided into the following  
22 three subquestions:

23

- 24 1. Do students in the experimental condition acquire more knowledge and a  
25 better understanding of mathematics and science?;
- 26 2. Do students in the experimental condition develop a better understanding of  
27 the use of models?; and do students in the experimental condition produce  
28 better models/drawings of their own products?
- 29 3. Do students in the experimental condition produce better models/drawings  
30 of their own products?

31

32 Finally, Study 3 (a quantitative study of the second experiment) addressed the  
33 following question: by designing a real product themselves, guided in a co-con-  
34 structive way, do students gain codified knowledge and a better understanding  
35 of modelling? However, since the test data did not show significant results at  
36 the level of condition (experimental treatment) we continued with Study 4 (also  
37 incorporating additional qualitative data) in order to find the determinants that  
38 might explain the differences in learning outcome at school level. The first goal  
39 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 were 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.

1  
2  
3 **Let the video be your guide:**  
4  
5 **A case study of video-based design research\***  
6

7  
8 **Abstract**  
9

10 In this article the iterative process of a design-based research project using video  
11 as one of the data sources will be reported. During the iterative design and im-  
12 plementation processes video recordings of teachers and students were used to  
13 provide guidance through the practical and conceptual changes. The video was  
14 an indispensable data source. Without it there would have been no possibility  
15 of 'seeing' how the curriculum project was enacted nor what the explanations  
16 for several results based on other data might be. We explain how our video data  
17 guided our academic analysis at three levels, the baseline level, the methodologi-  
18 cal level and the meta-level. With hindsight we are able to see that the extensive  
19 use of video data co-determined the course of the research trajectory in ways that  
20 would not have been possible with quantitative data alone. Through the use of  
21 video data we attempted to find an answer to questions of codified knowledge in  
22 knowledge-rich workplaces, simulated in vocational education. On the basis of  
23 our research experiences we conclude that video observations are indispensable if  
24 our aim is not only to improve theory and practice but also to reflect on the de-  
25 sign of the method itself; especially if design research is regarded as open-ended,  
26 and the agency of participants is valued.

27  
28 \* This chapter will be submitted as an article.  
29

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## Introduction 1

2  
This study reports on the iterative process of a design-based research project using 3  
video as one of the data sources. The overall research question of the project was: 4  
*Do students, who participate as model designers in a process of guided co-construction 5*  
*with an expert (teacher) and peers, show better learning outcomes than students who 6*  
*learn to work with ready-made models provided by the teacher? 7*

8  
During the project, between 2005 and 2010, six schools with over 30 teachers 8  
and 200 students were studied. More than 100 hours of video data were gathered<sup>2</sup>. 9  
In what follows a post hoc analysis of video data use is described with the aim of 10  
determining the value and role of video in our research; thus showing “how we 11  
came to know” (Goldman, 2007, p. 29). The research project was design-based 12  
(Barab & Squire, 2004; Shavelson, D.C. Phillips, Towne, & Feuer, 2003; The 13  
design-based research collective, 2003), started with the design of an educational 14  
curriculum project and ended with an experiment at four schools. We collected 15  
data on seven schools in three stages over three years. Figure 2.1 shows an over- 16  
view of the research time-line. 17

18  
As is often the case with this kind of research many changes and reorientations 19  
were made along the way. We had to take design decisions before and during the 20  
implementation of the intervention (Cobb, Zhao, & Dean, 2009). At the begin- 21  
ning of the research project there was little experience in the Netherlands concern- 22  
ing research in workplace simulations in preparatory senior secondary vocational 23  
education (vmbo)<sup>3</sup>, and no guidelines for video research in the learning sciences 24  
had yet been formulated (Derry et al., 2010). During the iterative design and imple- 25  
mentation process video recordings of teachers and students were used to guide us 26  
through the practical and conceptual changes. In addition, video helped us develop 27  
our theoretical framework and guiding principles (Terwel & Walker, 2004). 28

29  
With hindsight, the use of video played a significant role in that it guided 29  
research development at three levels. Starting with educational practice, video 30  
helped us to see and understand how the designed curriculum project worked in 31  
the classrooms. We call this the baseline level, since actual classroom practice was 32  
the unit of analysis. The designed educational intervention could be (re)viewed 33

34  
2 This is an estimate since almost all video was digital and compression methods 35  
have changed, it is hard to calculate the actual hours of classroom footage. 36

37  
3 Preparatory senior secondary vocational education is the official English translation 37  
used by CEDEFOP for Dutch vmbo. It is pre-vocational education for 12-16 year old 38  
students. About 60 % of Dutch students attend this type of education. vmbo was 39  
introduced in 1998. From her onward we will use vmbo. 39

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

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

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

26

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

30

31

## Theoretical framework and method

32

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

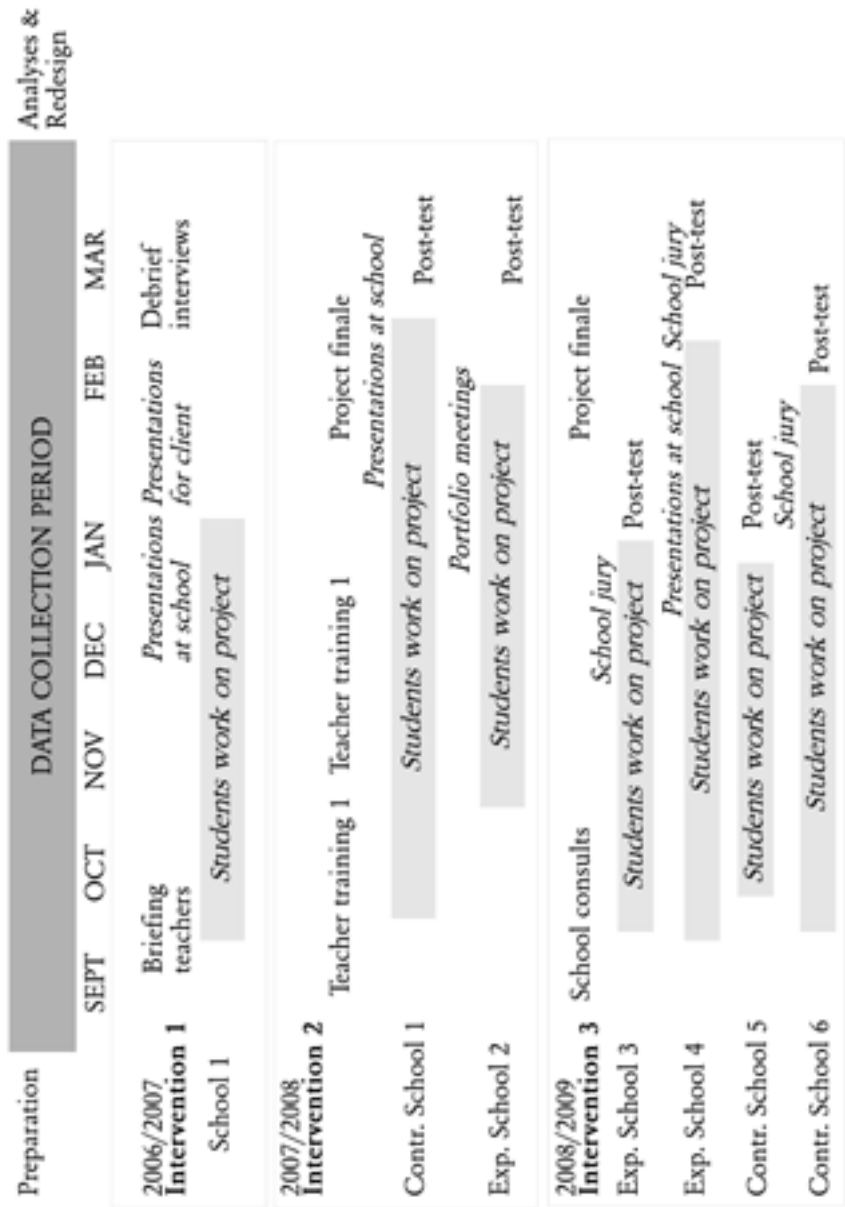


Figure 2.1 Time-line of the research.

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

7 The challenge to schools lies in formulating assignments that are meaningful  
8 for the students and realistic for their future work (Tuomi-Gröhn & Engeström,  
9 2003; Volman, 2006). At the same time, such assignments should also result in  
10 highly qualified learning outcomes that enable students to recontextualize and  
11 translate their knowledge and skills from the classroom to the workplace and vice  
12 versa. Guile and Young (2003) suggest knowledge-rich workplaces to support the  
13 recontextualization of situated knowledge into codified knowledge.

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

31 From the theoretical framework above four guiding principles were formu-  
32 lated for the design of innovative practices. First, the student assignments had  
33 to be meaningful; that is, resembling workplace tasks related to students' pos-  
34 sible future vocations. Secondly, assignments had to be complex enough to  
35 enable students to learn more than just vocational skills. Real workplace activi-  
36 ties could increase the need for specific knowledge and skills and subsequently  
37 provide opportunities for learning. Following Guile & Young (2003), such a  
38 workplace may be characterized as a knowledge-rich workplace (p.73). They  
39 are assumed to engage students in meaningful activities and at the same time

promote subject matter learning (such as mathematics; see Kent, Noss, Guile, 1  
Hoyles, & Bakker, 2007). The product to be constructed should be new to the 2  
students and challenging in such a way as to require the creation of models, 3  
plans and calculations. Such a process might lead to a recontextualization of 4  
previously learned codified knowledge in a new situation. Third, the students 5  
had to collaborate on the cooperative construction, as well as there mutual 6  
communication while focusing and reflecting on their models. Fourth, the 7  
schools had to be adapt and adjust the intervention to their local conditions. 8  
The curriculum project therefore needed to be adjustable while the core of the 9  
assignment goals had to be maintained. 10

For our study we designed an educational curriculum project for vocational edu- 11  
cation. Students had to design and construct a tandem tricycle for approximately 12  
five-year old elementary school pupils. Teachers were to guide their students in the 13  
design and construction process. For about 10 weeks students, together with the 14  
teachers, worked at this construction task in groups of three to five in large school 15  
workplaces, while solving problems and gaining new knowledge to get the work 16  
done. We closely studied the way in which teachers guided the students and tested 17  
the knowledge gained during that process. The data came from three separate stag- 18  
es: at the first stage one initial design of the curriculum project was implemented 19  
at one school and qualitatively analyzed as a case study (Van Schaik et al., 2010a); 20  
the curriculum project was redesigned on the basis of the results. The following 21  
two stages consisted of two experiments. In these experiments the redesigned cur- 22  
riculum project was tested, at two schools and four schools respectively. At the 23  
latter stages we collected video observations in addition to test data on knowledge, 24  
understanding and student characteristics. 25

The approach of the complete research project could be characterized as design- 26  
based (Barab & Squire, 2004; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; 27  
The design-based research collective, 2003). This methodological approach needs 28  
further explanation. 29

Since our theoretical framework had a Vygotskian foundation, according to 30  
Bell (2004), the project could be labeled cultural psychology design-based re- 31  
search which “... .. attends to the local cultural–historical foundations of develop- 32  
ment and learning as it is promoted and transacted through patterned interac- 33  
tions between individuals and artifacts” (p. 247). As the teachers were constantly 34  
involved in the development of the intervention together with the researchers the 35  
concept of mutual appropriation may be the proper way to understand our itera- 36  
tive design process (Downing-Wilson, Lecusay, & Cole, in press). For Engeström 37  
(2009) acknowledging the role of the teachers as actors who in the end shape the 38  
intervention is one of the characteristics of research based on a Vygotskian foun- 39

1 dation. In addition, since our aim is also to "... generate *intermediate* concepts  
2 and solutions that can be used in other settings as tools ..." (Engeström, 2009, p.  
3 321, italics added), and given that such solutions are not known ahead of time,  
4 our methodology could be characterized as a formative intervention.

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

10 All in all we collected more than 100 hours of video data over the three re-  
11 search stages. The video data consisted of classroom data (including interviews  
12 supported by classroom footage) and co-design data (including member check-  
13 ing, cf. Stake, 1995).

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

27

28

### **The baseline level: The research narrative**

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

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



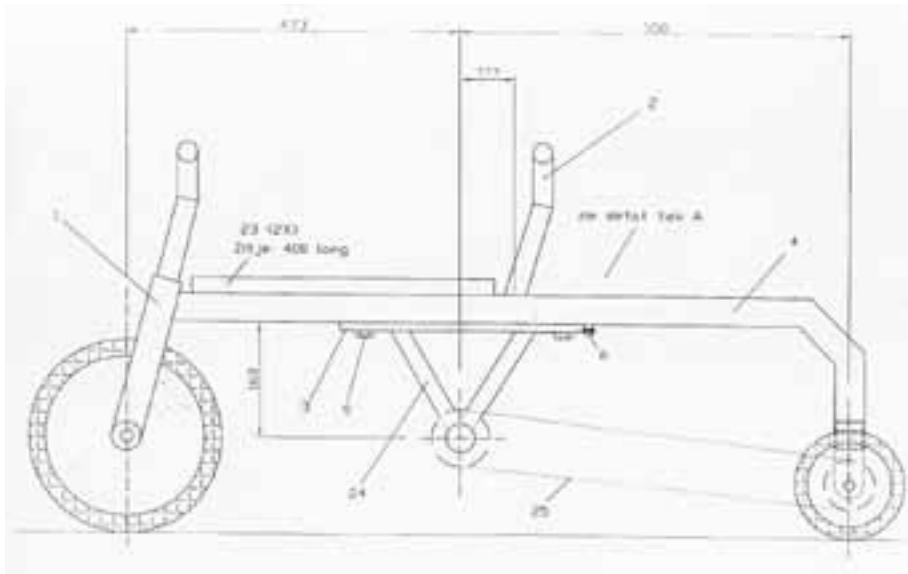


Figure 2.2 Technical drawing of students' design drawn by the teacher

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

13

## 14 Case study

15

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

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

33

34 »ε *Video 2.1 Video samples supporting case study findings*<sup>4,5</sup>

35

36

37 4 »ε (ε from extra and the Greek word εἶδον, to see) indicates an extra video sample  
38 which can be found at <http://mvsjtbvo.video-research.eu> after registration.

39 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 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 integration 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

1 significance for the students was explained, while the opportunities for modeling,  
2 based on the first study, were highlighted. During this session we used clips from  
3 the case study video data to illustrate what the intervention might look like.  
4 We asked the teachers how they thought they might implement the interven-  
5 tion. Their suggestions were worked out during the summer vacation, result-  
6 ing in two separate programs, since we planned to conduct an experiment in a  
7 pretest posttest control group design. This was to mirror the difference between  
8 the conditions to be enacted: teachers in the control condition would provide  
9 models to the students, whereas teachers in the experimental condition would  
10 guide students in collaboratively constructing the models themselves. It should  
11 be noted that schools were assigned to the conditions depending on their current  
12 pedagogical practice, which we determined during school visits and subsequent  
13 meetings. The teachers were allocated to the condition that best fitted their cus-  
14 tomary approach to teaching (providing or guiding co-construction).

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

25 The quantitative analysis of this intervention showed no difference between  
26 the conditions with respect to scores on the posttests on knowledge codified  
27 from the disciplines (maths and mechanics). However, as rated by modeling  
28 experts, the students in the experimental condition produced better models  
29 of their products. Interestingly, analysis of the video data showed that the stu-  
30 dents' models (i.e. the construction drawings) disappeared during the process  
31 of construction, and were no longer visible in the observations. Video 2.2 shows  
32 typical of week 3 and week 6 sequences at School 2, starting with week 3 se-  
33 quences with students working on, and using their drawings, followed by week  
34 6 sequences without drawings.

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

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38 Again we went back to the schools with these analyses of the test and video data  
39 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 1  
in the control condition, again, were very constructive and confirmed our first 2  
analysis. Their main point was that students should be taught how to draw and 3  
design on separate occasions, since they were patently incapable of doing that: 4

Excerpt 2 5

Teacher (control condition): [I] don't ask them to do the drawing themselves [the 6  
technical design model], because they simply can't. 7  
8

The teachers in the experimental condition intimated that they had been skeptical 9  
from the start, since they thought students needed more guidance. Looking back at 10  
the video recordings of the training sessions from the start of the project onwards, 11  
we could confirm that the teachers had in fact been skeptical. However, at that time 12  
they did not express their skepticism verbally. Video 2.3 shows shots of this training 13  
as well as the teachers' body language and some of their utterances. 14  
15

*»ε Video 2.3 Shots of the teacher training session 16*

The classroom video showed that the guidance students received had in fact been 17  
minimal, focusing on assignment planning and finishing. 18  
19

All in all, the test results did not show any significant differences between the con- 20  
ditions; the video data did however. We concluded that in spite of the small amount 21  
of guidance students received in the experimental condition, their performance was 22  
better on modeling due to the focus on the process and the use of models as tools 23  
for communication and orientation (Van Oers, 1988; Van Schaik et al. submitted a). 24  
25

On the basis of our previous experiences we decided to design a new series of 26  
separate prototype lessons on designing. The only difference between the condi- 27  
tions was the way the lessons were enacted: in the control condition they were 28  
planned ahead, whereas in the experimental conditions the lessons were taught 29  
ad hoc or more or less 'on demand'. The student assignment remained the same. 30

## Final experiment 31

Following the same time schedule as in the first experiment, we selected four 32  
schools (n=87) in the spring and explained our plans, again with the use of video. 33  
We did not organize any collective training sessions, nor any teacher trainer help, 34  
since the program for the schools was strict. However, it was the teachers that chose 35  
their own method of implementation. This meant that, apart from fitting the pro- 36  
gramme into their schedules, they had to find a way of implementing the proto- 37  
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39

1 type lessons and connect them to the practice workplaces. In two cases it was the  
2 teacher that was the connection: he taught both practice and the design lessons. In  
3 the other cases the prototype lessons were planned during mathematics periods.  
4 Schools were assigned to a condition in the same way as in the first experiment, and  
5 the implementation again took 8-10 weeks. The collected data was similar to that  
6 of the first experiment. The video observations differed in frequency since we had  
7 more schools to attend. We therefore focused on the crucial weeks in the process:  
8 the beginning, the period between weeks 3 and 6, and the end.

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

26

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

28

29 At the baseline level the video was one of the data sources that led to our con-  
30 clusions in the separate studies. In other words, the baseline level described the  
31 findings from the video data. At the methodological and meta-levels we looked  
32 for the changes in the video and examined their correspondence with the meth-  
33 odological and theoretical changes.

34

### 35 **The methodological level: adjustments to the intervention** 36 **and method**

37

38 Before we continue and discuss the way video informed the design process we  
39 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 Base-line 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) - Reflection on production process may lead to recontextualisation (prototype) - Also quantitative data
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		

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

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

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

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

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



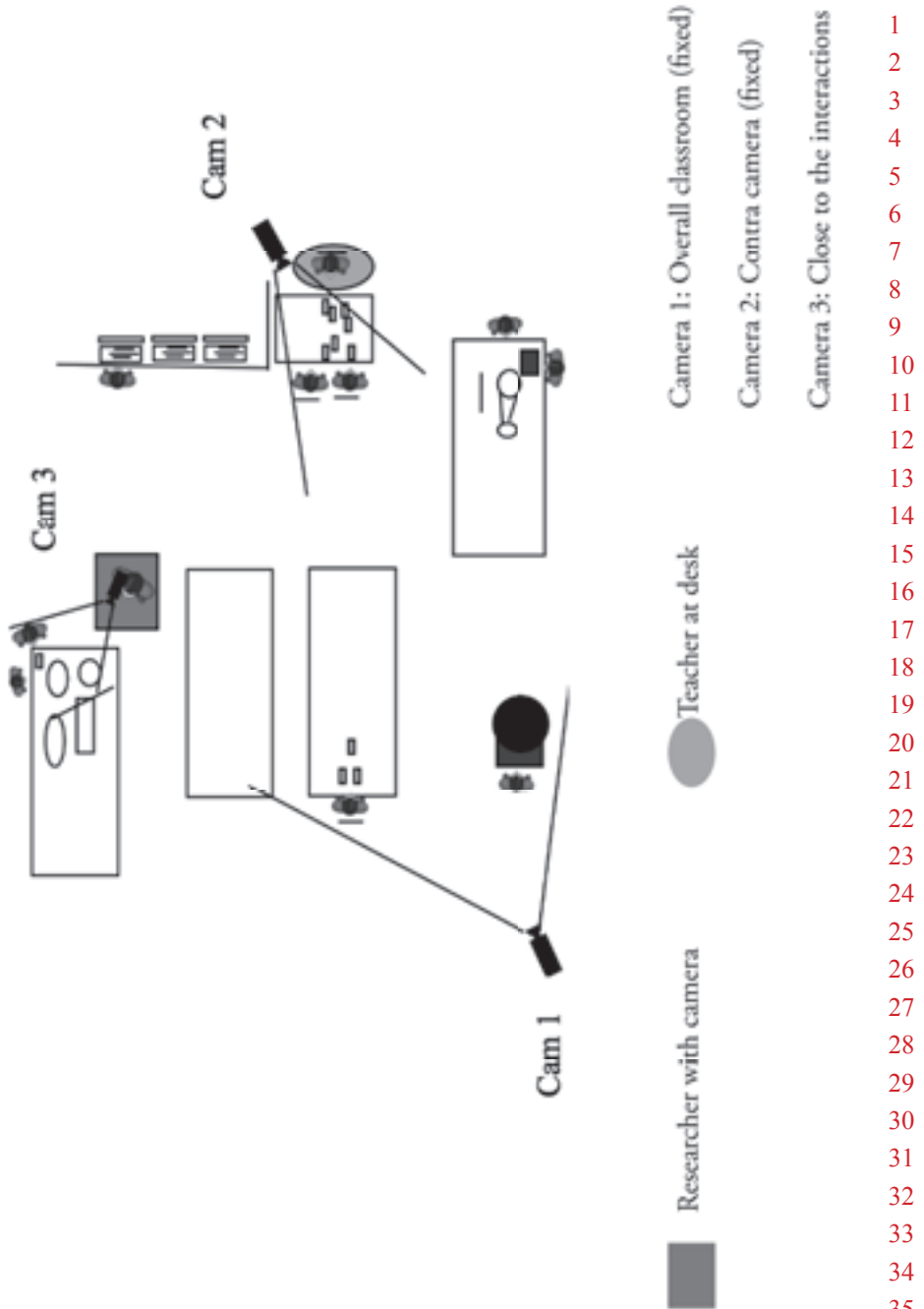


Figure 2.3 Video data collection in the classroom

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

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4

»ε *Video 2.5 Panoramic overview of simulated workplace*

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

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

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

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

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

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

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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

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

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»ε *Video 2.6 Students' camera awareness*

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

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

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### **The meta-level: shifting perspectives**

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

37 From these intervention adjustments (to the curriculum project and the  
38 method) we already notice a growing insight into modeling in knowledge-  
39 rich learning environment. In the case study the research was still explora-

tory, 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 from 30 hours to 20 hours, and eventually to less than 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 questions 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?*

1 For the final experiment:

2 Study A: *By designing a real product themselves, do students, guided*  
3 *in a co-constructive way, gain codified knowledge in math-*  
4 *ematics and science and a better understanding of model-*  
5 *ling?*

6 Study B: *What was the actual teaching/learning practice in the*  
7 *schools and how did the schools differ, especially in how the*  
8 *models functioned as tools in the design process?*

9 *Was the teaching/learning practice aimed at designing and*  
10 *understanding related to the disciplines, both the academic*  
11 *and the vocational?*

12

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

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

39 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

1 directly visible in the data, the adjustments that were actually carried out could  
2 be reviewed only after the redesigned intervention had been reimplemented. The  
3 present analysis as such is a triangulation of our design process after the fact,  
4 which would also have been impossible without the video data.

5 With hindsight we see that the extensive use of video data co-determined the  
6 course of the research trajectory in ways that would not have been possible with  
7 quantitative data alone. On the basis of the quantitative data we would have  
8 concluded that the project's research conditions (providing codified knowledge  
9 versus co-constructing) had not worked out as predicted in the context of knowl-  
10 edge-rich environments. On the basis of our workplace observations we were able  
11 to refine the design's guiding principles and conduct a replication study, which,  
12 as it happened, yielded basically the same answers to our main research ques-  
13 tions. Further, the video data from students' and teachers' workplace activities  
14 enabled us to discover in the redesigned project that the design and use of the  
15 models differed for the various schools in. The data even enabled us to speculate  
16 about conditions that might be conducive to such situations. As a result, our at-  
17 tempts to find answers to our original research questions concerning the learning  
18 of codified knowledge in simulated knowledge-rich vocational education work-  
19 places obviously needed theoretical refinements that no longer focused on deter-  
20 mining the value of broadly defined conditions such as 'guided co-construction',  
21 but concentrated on actual microgenetic learning trajectories in the use of mod-  
22 elling (as a tool for orientation and communication) and the way this process  
23 was guided by discussions and appropriately tuned-in instructions by an expert  
24 (teacher). It is our contention that a decade of studies on the issue of providing  
25 versus co-construction has reached a new stage with detailed video-analysis. Such  
26 studies should in our view be defined as studies of providing in the context of  
27 guided co-construction and as studies of the ways co-construction may support  
28 the meaningful use of tools and codified knowledge in students' problem solving  
29 when engaged in processes of construction and design.

30 In addition, the video data functioned not only as our source for analysis or  
31 as a tool for interviews and participant member checking, it also brought the  
32 intermediate concepts and solutions (Engeström, 2009) back to the schools. For  
33 example, when we showed the observation videos to the teachers, one of the ef-  
34 fects was that the video data informed the teachers of their own practice and our  
35 perspective on it. If design-based research is to improve theory and practice, and  
36 if it is to be regarded as an open, non-linear process with acknowledgement of the  
37 participants' agency, then relaying the insights to the workshop should be a part  
38 of the research. The Vygotskian notion of double stimulation (Engeström, 2009)  
39 could thus be extended to triple stimulation: The first stimulus in the formative



intervention would constitute the problem, the second stimulus the tool (in- 1  
tervention program) as adapted by the participants, the third the intermediate 2  
concepts and solutions brought back to the participants. The cycle would thus 3  
be closed and, by way of a next step, a new problem might be formulated and 4  
research continued. 5

We believe to have demonstrated that video is not just a rich data source. We 6  
also believe it to be indispensable in design research if our aim is to improve 7  
theory and practice and, in addition, to reflect on the method itself. Especially 8  
if we regard design research as open-ended and value the agency of participants. 9

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### 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 re-constructing it, and towards the end of the project, knowledge tended to remain situated.

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## Learning in preparatory vocational education 1

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Over recent decades, Dutch preparatory senior secondary vocational education<sup>6</sup> 3  
(vmbo) has gone through different radical changes. Traditionally, this educa- 4  
tion was mainly focused on training technical and vocational skills. However, in 5  
the 1980's, theory-based learning became the focus in vmbo. Neither of the two 6  
approaches was satisfactory. The first (practical) approach could not optimally 7  
stimulate the broad development of students, the second approach was often too 8  
difficult or resulted in meaningless mechanical learning. 9

10 Within the European Union and elsewhere it is recognised that in order to 10  
prepare students for the demands of the future, they should obtain competen- 11  
cies that cover both broad general knowledge as well as technical skills (Cedefop, 12  
2009; Commission of the European Communities, 2008). However, there is an 13  
ongoing debate on how to connect formal learning and learning in the workplace 14  
(Billet, 2003; Griffiths & Guile, 2004; Guile & Griffiths, 2001; Tuomi-Gröhn & 15  
Engeström, 2003). 16

17 By observing current vmbo classrooms, and interviewing students and teach- 17  
ers, a new approach to learning in vmbo has emerged. As an attempt to improve 18  
the relevance of the knowledge and the effectiveness of the transfer to the work- 19  
place, like in other countries, a reform is taking place in vmbo schools (Guile & 20  
Young, 2003). Students and teachers learn together while they work on products 21  
for “real” customers. The basic assumption behind this approach is that learning 22  
of subject matter knowledge and vocational skills can be integrated in authentic 23  
workshop practices. However, knowledge, for example knowledge about model- 24  
ling or knowledge gained in mathematics education lessons, is often not used for 25  
problem solving in a workshop setting. Students often do not recognize the rela- 26  
tion between theory and practice, which results in a reduced learning outcome 27  
and lack of motivation on the part of students. The challenge for schools is to 28  
provide assignments that are meaningful for the students and realistic for their 29  
future work (Volman, 2006). At the same time, those assignments should also re- 30  
sult in highly qualified learning outcomes that enable students to recontextualise 31  
their knowledge and skills from the classroom to the workplace. Teaching should 32  
support a meaningful link between both practical problem solving and subject 33  
matter knowledge (Van der Sanden, Terwel, & Vosniadou, 2000). 34

35 Real workshop activities could increase the need for specific knowledge and 35

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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).

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

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

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

19 Adopting the idea of knowledge-rich workplaces for teaching models and  
20 modelling practices in vmbo, however, raises a number of questions. Is it really  
21 possible to base knowledge and skill acquisition in vmbo on this approach?  
22 What is the quality of the learning outcomes (in terms of deep-level under-  
23 standing or flexible application)? How should learning processes, embedded  
24 in practical work, be managed by a teacher? In our research project, some of  
25 the questions related to the guidance of learning processes in knowledge-rich  
26 workplace settings in classrooms are addressed. In particular, how teachers as-  
27 sist students in acquiring necessary skills and knowledge regarding the design  
28 of useful construction models for the accomplishment of their assignment was  
29 explored. As a first step, a case study was conducted in which teacher - student  
30 interactions in a knowledge-rich workplace setting were closely observed. In  
31 this case study, the theoretical framework and the concept ‘modelling’ will be  
32 first be further described. Second, the research methods and the way in which  
33 the curriculum project was developed and implemented in the school will be  
34 described. Next, a qualitative analysis of occurring patterns is conducted ad-  
35 dressing the following specific questions: *which teaching/learning processes occur*  
36 *in a simulated workplace using the concept of a knowledge-rich workplace, and*  
37 *what is the role of models and modelling?*

38

39

## Models and modelling in knowledge-rich practices 1

2  
3 Focusing on modelling in teaching-learning processes requires a further expla-  
4 nation of the cognitive functions of models, of how models and modelling are  
5 conceived, and of how models can be meaningfully integrated in the teaching  
6 process.

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

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

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

31 Models can be seen as structured tools that facilitate problem-solving activi-  
32 ties. Models have two core functions: orientation and communication, which  
33 are not mutually exclusive. Orientation, according to Gal’perin (1976, in Van  
34 Oers, 2006), is an essential moment of cultural action. A model, according to  
35 this point of view, is a cultural tool for orientating on actions to be performed  
36 (Van Oers, 2006). Like a map helps to plan a trip, the model gives direction to  
37 a person’s activities. As orientation is a cognitive activity, it includes valuation,  
38 producing information, planning, predicting, etc. As tools for communication,  
39 models foster the distribution of individual ideas and meaning across the com-

1 munity. When, for example, students work together on the construction of a tri-  
2 cycle, the drawings, plans and ideas (i.e. the models) are used to plan the process,  
3 predict problems and discuss the final design. The models give direction to the  
4 actual design and the planning of the activities, but also coordinate the ideas and  
5 actions among the participants. In other words, the models help to anticipate the  
6 outcome (Gal'perin 1969; 1979 in Van Oers, 2006), and to distribute meanings  
7 in a community.

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

28 Since the way students learn to model while they work and learn in a workshop  
29 at school will be studied, it is necessary to know what kinds of knowledge the  
30 workshop requires. In the learning processes of students, changes in the sort of  
31 knowledge the students have to acquire and use are examined. Guile & Young  
32 (2003) distinguished between different kinds of knowledge: tacit vis-à-vis situ-  
33 ated; situated vis-à-vis codified; and codified vis-à-vis disciplinary. The authors  
34 make these distinctions because learning in workplaces is not only a process of  
35 participation, "but it also involves the acquisition of knowledge which may not  
36 be available in the 'communities of practice' in which [students] find themselves"  
37 (p.66). Hence, learning environments (in and outside school) which aim to teach  
38 more than just skills should be knowledge-rich.

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

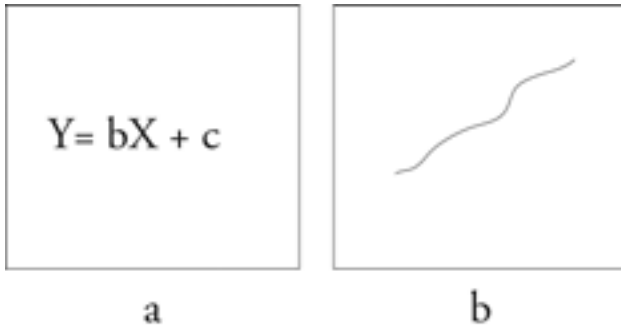


Figure 3.1 Canonical and situational model

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 modeling, codified or disciplinary models should be brought to bear in the community of practice in which teacher and students work together.

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

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

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

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

31 In this learning environment, the guidance of the teacher is crucial. The present  
32 case study explores the processes that develop as a result of this guidance. Does  
33 this guidance bridge the gap between problems students already can solve with-  
34 out help, and problems for which the students still need the help of the teacher  
35 (the expert)? This is what Lave and Wenger (2005) and Daniels (2005) called the  
36 'scaffolding' interpretation of the zone of proximal development (ZPD). Although  
37 many different interpretations and descriptions are available, a core element is  
38 that scaffolding is an interaction process and thus dynamic (Renninger, Ray, Luft,  
39 & Newton, 2005; Van Geert & Steenbeek, 2005). As Stone (1993) pointed out, in



many school-based applications of the scaffolding notion, something is seriously 1  
missing. Many examples of scaffolding lack the possibility for the students to see 2  
where the scaffolding process is bringing them. In other words, students cannot 3  
see the relevance of the guidance in respect to reaching their immediate goals. 4  
This opportunity to give meaning to the scaffolding process on the basis of a fi- 5  
nal, long term goal is called *prolepsis*. The lack of prolepsis is, according to Stone, 6  
a serious drawback of scaffolding in meaningful educational processes. Due to 7  
their nature, knowledge-rich learning environments optimally enable students to 8  
see the relevance of scaffolding for their work and to accomplish this prolepsis. 9  
The distant goal of their activity is clear and students can meaningfully relate to 10  
every step, and to the teacher's comments to this final goal. Adaptation of the ap- 11  
propriate scaffolding strategy is the key goal of a teacher. In addition to the con- 12  
struction of situational models (construction plans) for the construction of the 13  
product (a tricycle), the objectives of the learning processes which are embedded 14  
in knowledge-rich workplace simulations are the (re)construction and appropria- 15  
tion of knowledge from the domains of mathematics and natural sciences. In this 16  
study, the way in which the goal of the teacher and the objectives of the learning 17  
process are addressed in the classroom and workshop setting, will be analysed. 18

## Method 20

The research project is *design based* (Shavelson, Phillips, Towne, & Feuer, 2003; 22  
The Design Based Research Collective, 2003), which means in our case that the 23  
first draft of the curriculum project was designed on the basis of available theory 24  
and in cooperation with experienced teachers. This project is studied in action in 25  
the first phase. In the second and third phase, it will be redesigned and used in an 26  
experiment with a control group. In this article, the first implementation of the 27  
designed curriculum project in a case study design is reported. 28

### Curriculum project 30

During a period of twelve weeks, students (aged 14-16 years) had to choose what 32  
to design and construct: in subgroups of three or four for a 'real' client: a tandem 33  
tricycle or a bicycle game. The clients were a primary school principal and the 34  
owner of a party centre who were willing to buy the final products. Working for 35  
those clients provided a basis for the students' prolepsis during the design process, 36  
as in order to satisfy the clients, the students had a real interest in the quality of 37  
their final products. Initially, the assignment for the students was formulated in 38  
just a few sentences: 39

1 *Please design and build:*

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

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

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

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

28 With the help of the teachers, this curriculum project was constructed on the  
29 basis of several design and construction tasks for students in Dutch preparatory  
30 vocational education. A case study methodology was used to study the cur-  
31 riculum project (Yin, 2006). The objective of this case study was to determine  
32 if and how the concept of guided co-construction of subject matter knowledge  
33 and models was visible in the practical application of the curriculum project in  
34 action, and whether the learning environment actually became knowledge-rich.  
35 Consequently, the learning processes of the students and the learning environ-  
36 ment were the main foci, and the research questions were: which educational  
37 processes occur in a simulated workplace using the concept of a *knowledge-rich*  
38 workplace? The criteria for determining if it was a knowledge-rich workplace  
39 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”<sup>7</sup> 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)<sup>8</sup>. Team B consisted of Joost and Mohammed (both basic

---

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.

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

3

#### 4 **Data collection and procedures**

5

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

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

30

#### 31 **Pattern Analyses**

32

33 The video data was subjected to multiple viewings to explore the footage for pat-  
34 terns. We used this method, known as pattern analysis (Erickson, 2004; Terwel,  
35 2005), to allow the observers watching the videos to detect patterns in the data.  
36 These patterns are called *a posteriori* patterns. A pattern is a formal description of  
37 a repeating structure in interviews and in interactions. Patterns can be mentioned  
38 by the participants in interviews or can be noticed by the researcher during ob-  
39 servation. 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<sup>9</sup>), 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.

### Pattern 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.

---

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

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

14

#### 15 1.2 *Episodes*

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

22

#### 23 Excerpt 1.1

24 Mr Williams: Ok, let's see. I found out that a [front] cogwheel cannot be  
25 (technology teacher) smaller than 30-32 teeth. Yeah? A separate cogwheel  
26 which one can normally attach to the back axis of a  
27 bike only seems be available with less than 20 teeth.  
28 So we have a ratio of one and a half (...) If we measure  
29 the distance the bike rides in one pedal turn, we can  
30 calculate (...) how much the other has to pedal. Agreed?  
31 Then we have to know the measurements of these tires  
32 [draws them ] (...) Do you think you can calculate this,  
33 with help of another teacher?

34 Ryan: We have to do that with Mr. Quinten's help (maths  
35 teacher).

36 Sander: What do you need to calculate this?

37 Ryan: A calculator.

38 Mr Williams: If this wheel turns once, how much does the child need  
39 to pedal? That's what I want to know.

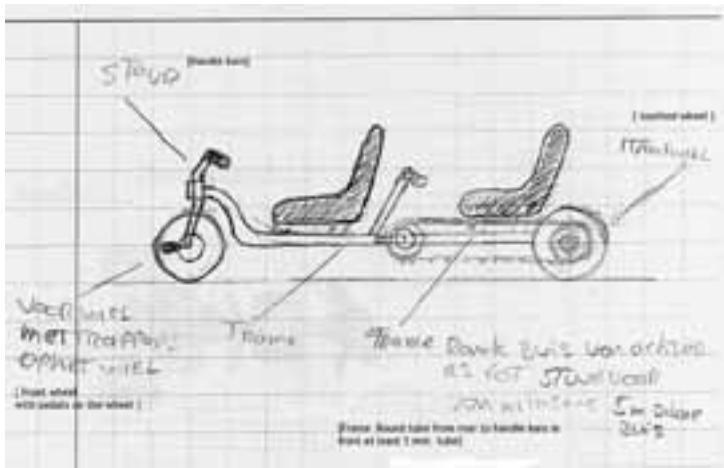


Figure 3.2 First draft of design of tandem tricycle drawn by students

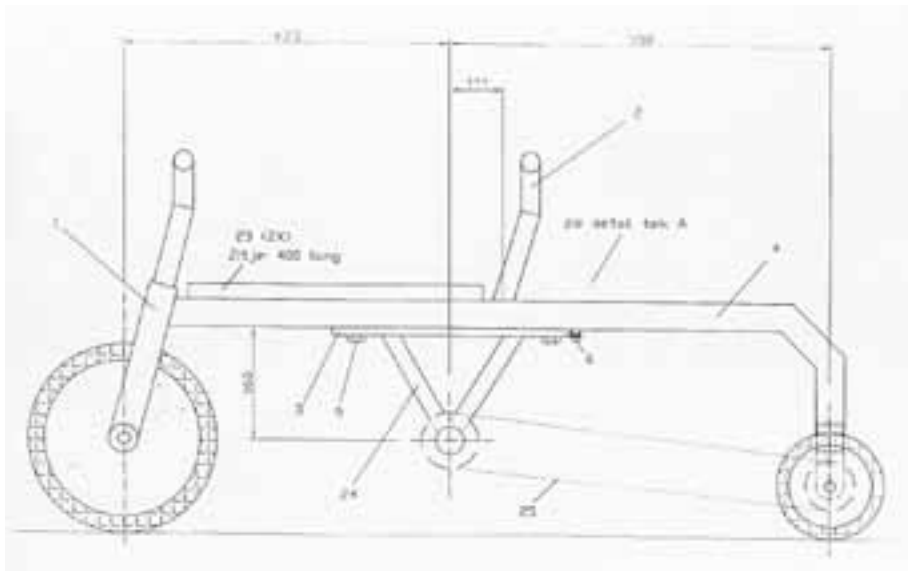


Figure 3.3 Technical drawing of students' design drawn by the teacher.

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

3  
4 In a conversation at the start of the lesson, the teacher checks if the students  
5 eventually found a solution to the problem. We can hear that some homework  
6 has been given.

7  
8 Excerpt 1.2

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

12  
13 In the classroom with the computers, the teacher gives Sander a design job to do  
14 at home.

15  
16 Excerpt 1.3

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

20  
21 Later on in the process, in week five, the teacher finds a problem concerning the  
22 position of the crank. The teacher, in his role as a member of the design team, has  
23 to look again at the technical drawing (Figure 3.3) he made :

24  
25 Excerpt 1.4

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

32  
33 In the final week, when Mr Williams is busy with many students, Sander asks  
34 him a question about the thickness of the steel. Mr Williams responds briefly and  
35 instructs Sander on how to resolve the issue of the steel. Sander's next question is  
36 about holes in the material:

37  
38 Excerpt 1.5

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



Mr Williams: Because if water runs in, it has to come out. 1  
2

In one of the first interviews with the teacher, he confirmed that one of his jobs is 3  
to make sure that a quality product will get finished in the end, and therefore he 4  
provides the technical drawings: 5  
6

Excerpt 1.6 7

Mr Williams: I think it is my job to get the project started well. I have tried 8  
it before, waiting until the students came up with their plans. 9  
But before you know, a week has past and then the plan of the 10  
project ends up in a folder or so. 11  
(...) 12  
If I didn't do anything, in the end a pedal will be welded some- 13  
where randomly, a chain spanner forgotten and those kinds of 14  
things. There will be a product in the end, but I would not want 15  
to have it sent out to the client. 16  
(...) 17  
Let alone that they [the students] have to make a construction 18  
drawing, they are simply not up for it. The drawings and sketch- 19  
es they make, do not resemble a technical drawing. It think that 20  
it is my job to make a drawing they can work with. 21  
22

1.3 *Conclusion* 23

The workplace is the place where the product has to be built. Therefore, the 24  
teacher is mainly concerned with getting things done and with the quality of 25  
the products. Although the teacher (Mr. Williams) sometimes tries to elaborate 26  
further on general issues, and tries to give students time to think about and 27  
understand mathematical issues (e.g. the concept of ratio), more often the stu- 28  
dents are referred to the teachers of the relevant subject, who in turn provide 29  
a solution (see excerpt 1.1. and 1.2). In the workplace, design tasks during the 30  
construction phase are homework (see excerpt 1.3). This may reflect what hap- 31  
pens when the school becomes an authentic workplace: the client and product 32  
are the main concern of teacher and students. Consequently, learning or apply- 33  
ing theoretical knowledge in order to advance the use of disciplinary models, 34  
has to be done somewhere else. 35

In and shortly after the design phase, there are opportunities for students to re- 36  
contextualise situated knowledge about design and construction by students, to 37  
codified or even disciplinary knowledge (Guile & Young, 2003). That is, from a 38  
separate design problem and its solutions, the students are guided to apply more 39

1 general rules and subject matter content. The dialogue between the students and  
2 the teachers can guide the students to reinvention of knowledge that is suitable for  
3 their problem; though this knowledge is generative in a sense that it becomes clear  
4 for the students that it can be used as a rule or a problem solving strategy. Later  
5 on the possibilities to recontextualise become scarce. The team and the teacher are  
6 working towards a deadline, and there is no time for elaboration. The tips and tricks  
7 students receive in this phase have the form of situated knowledge.

8  
9 **Patern 2. Problem solving starts with modelling, but solutions are often**  
10 **provided.**

11  
12 2.1 *Introduction*

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

24  
25 2.2 *Episodes*

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

29  
30 Excerpt 2.1

31 Mr Quinten:

32 (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.

33  
34  
35

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

39

Excerpt 2.2		1
Sander:	We had to know how big the toothed wheel had to be.	2
	Then we asked the maths teacher to calculate it for us.	3
	Euh, with Mr. Quinten's help we calculated it.	4
		5
	The three students need to know the length of steel they need. Mr Williams explains that they should use Pythagoras' theorem: (Excerpt 2.3)	6
		7
		8
Excerpt 2.3		9
Mr Williams:	When you have an equation with only one missing variable, you can calculate that variable. Can you do that?	10
		11
		12
	<i>[Students try, randomly, some figures]</i>	13
Ron:	Oh, euh, $a + b = c$	14
Mr Williams:	No, that's not what it said; $c^2 = a^2 + b^2$ .	15
		16
	<i>[Finally one of the students comes with the solution to take the square root]</i>	17
		18
	In an interview, the teacher reacts on the question 'who designs what?':	19
		20
Excerpt 2.4		21
Mr Williams:	In this phase, I'll take the lead. I have to make sure the ready made <i>[technical]</i> 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.	22
		23
		24
		25
		26
		27
		28
2.3 Conclusion		28
	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).	29
		30
		31
		32
		33
		34
		35
		36
		37
		38
		39

## 1 Patern 3. A workplace simulation is stimulating

2

### 3 3.1 *Introduction*

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

10

### 11 3.2 *Episodes*

12 Ryan, Sander and Alim are at the primary school for which they are making the  
13 tricycle. They are sitting in the office of the school principal, all looking very  
14 serious with pens poised to write down the answers to their questions (excerpt  
15 3.1):

16

17 Excerpt 3.1

18 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? (...)

22 Ryan:

I think we can deliver the bike to the school in January.

23

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

28

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

32

33 Excerpt 3.2

34 Ryan:

So we thought of doing it like this. (...)

35 Mr Williams:

But then you’ll have the problem that the tricycle will  
not turn easily...

36

37 Ryan intervenes:

Then we need to have one free wheel

38 Mr Williams:

Exactly!

39

In an interview Mr. Williams reflects on why and how the ('real') assignments work:	1 2 3
Excerpt 3.3	4
Mr Williams:	5
Products that roll, turn or ride are always interesting [for students].	6
A stranger as a customer can be much more important than I think	7 8
It is a exiting target group [ <i>the six year olds for the tandem tricycle</i> ]. It is very clear how, later on, the product will be used [ <i>by the client</i> ].	9 10 11 12
In a final interview with Ryan and Sander, they agree that they designed most of the tricycle themselves:	13 14 15
Excerpt 3.4	16
Ryan:	17
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.	18 19 20
Sander:	21
We still have to paint it to make it look better, although that [ <i>painting</i> ] isn't normally compulsory.	22 23
3.3 Conclusion	24
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.	25 26 27 28 29 30 31 32 33
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	34 35 36 37 38 39

1 to other teachers or were expected to find solutions as homework. Most models or  
2 knowledge therefore remained situated. Somehow, the teacher's guidance in the  
3 classroom stopped at the situated and practical issues, which may have been caused  
4 by the time limit of the assignment. Situated knowledge was at stake when for ex-  
5 ample typical problems in students' design, like where to attach the crankshaft to  
6 the frame of the bicycle, had to be solved. Codified knowledge was required when  
7 students learned how to find the right configuration of a welding machine. An ex-  
8 ample of disciplinary knowledge was found when the mathematics teacher explains  
9 how to solve the problem of transmission by using the ratio concept.

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

30

31

## Conclusion & discussion

32

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

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

Our analyses resulted in a description of three patterns. In sum, it appeared 1  
that the process of designing a new product for real clients created moments and 2  
opportunities for students to use and learn models and offered the possibility of 3  
prolepsis that helped to organizing the scaffolding process in a meaningful way. 4  
This meant that the learning environment became knowledge-rich, in that finish- 5  
ing the assignment required different types of knowledge and skills, and created 6  
opportunities for students to acquire situated, codified and disciplinary knowl- 7  
edge. However, the analyses showed that the knowledge tended to be provided 8  
by the teachers and was taken outside the workshop as homework or to other 9  
teachers. The ratio problem in the design of the tricycle was an example which 10  
illustrated both the potential of the assignment, and the tendency that while 11  
more general, codified and disciplinary models was provided by (other) teachers, 12  
the mathematics teacher simply provided the students with information on the 13  
way in which the problem could be solved. This tendency of providing canonical 14  
models was apparent when knowledge was codified or disciplinary, or when there 15  
was no time for elaboration due to the deadline of delivery. The only models the 16  
students really designed themselves, were the drafts of the first design, or situ- 17  
ational models. Models with more theoretical notions were provided and the use 18  
of these models was not further elaborated on by the teachers: hence models in 19  
the learning? process were mostly situated. Furthermore, students became truly 20  
motivated and owners of the problems when the client was “real”, which was 21  
apparent when they could not stop talking at their presentation in front of their 22  
peers, and expressed in an interview that they had designed most of the product 23  
themselves. 24

As mentioned above, a conclusion of the current study is that the assignment 25  
was knowledge-rich and was motivating for the students, as it aroused the need 26  
for further and more specific knowledge and skills. At the same time, codified 27  
and disciplinary models were mostly provided by the teacher and the students 28  
did not generate them themselves. Since there seemed to be many opportunities 29  
while working on the assignment to use and create models, the question is how 30  
to make the reinvention of canonical models as authentic as the situational solu- 31  
tions are. Or, in other words, how the learning potential of the assignment in 32  
the simulated workplace becomes realized (Nijhof & Nieuwenhuis, 2008). The 33  
learning environment might become knowledge-rich when the teacher guides the 34  
students in improving their modelling by bringing in his knowledge and the ap- 35  
propriate cultural tools in order to (co)construct qualitatively better models that 36  
are meaningful for more than the unique situation. In other words, helping the 37  
students to reinvent models usable as orientation and communication tools in a 38  
learning strategy may create a knowledge-rich learning environment. 39

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

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

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# 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

1  
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3 To strengthen the relation between theory and practice, schools for preparatory  
4 vocational secondary education (vmbo)<sup>10</sup> in the Netherlands and elsewhere are re-  
5 forming their curricula (Biermans, Nieuwen, Poell, Mulder, & Wesselink, 2004;  
6 Guile & Young, 2003; Mittendorff e.a., 2008; Boersma, ten Dam, Volman, &  
7 Wardekker, 2009). The reform is aimed at engaging the students in work-related  
8 school assignments. The general question arises whether such assignments in fact  
9 improve the relation between theory and practice, and what knowledge could  
10 be acquired by working on such authentic assignments; in other words, whether  
11 understanding is fostered and if so, to what extent. This general question prompts  
12 two processing questions: if improvement is found to be significant, how do con-  
13 cepts and models become tools in gaining understanding of the knowledge do-  
14 main they relate to, and how do they aid the search for solutions to practical  
15 problems?

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

36 \_\_\_\_\_  
37 10 vmbo is the Dutch name for secondary education for students 12-16 in their  
38 preparation them for senior secondary vocational education. Sixty percent of all  
39 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 1  
such teacher-guided processes as co-construction. 2

In our research we are interested in the construction of models and vocational 3  
knowledge in a rich learning environment. Research has shown that the strategy 4  
of guided co-construction may lead to a better understanding of mathematics 5  
and modelling than a strategy based on simply providing models (Doorman, 6  
2005; Terwel, Van Oers, Van Dijk, & Van den Eeden, 2009; Van Dijk, Van Oers, 7  
& Terwel, 2003). Reinventing the models under teacher guidance helps students 8  
understand the function and value of modelling (Gravemeijer, 1997). In addition, 9  
diSessa found that students are capable of (re)inventing models, e.g., graphs and 10  
drawings (diSessa, 2002;2004). Others have found promising forms of problem- 11  
based learning and problem solving programmes in real-life contexts (Kolodner 12  
et al., 2003; Hill, 1998). However, it is not clear how this type of model recon- 13  
struction is supposed to work when students work on real-life assignments in 14  
vocational education. 15

In the case study referred to earlier we implemented an authentic assignment at 16  
one school for preparatory vocational education. It was found that the teacher's 17  
guidance tended to be based on simply providing the students with ready-made 18  
models. Although the assignment clearly included many opportunities to help 19  
students gain a better understanding of mathematical and scientific models, 20  
the school's workshop culture was based on the precept to 'get things finished.' 21  
Hence, the use of models appeared to be situated and tacit, while the relevant 22  
knowledge and the models used remained situation-bound. Neither the model- 23  
ling process nor the relevant knowledge were explicitly reconstructed. Problem 24  
solutions in those situations were provided by the teacher, and no time was spent 25  
on further exploration of the mathematical and scientific concepts (Van Schaik, 26  
Van Oers & Terwel, 2010a). 27

In the present study we build on these previous findings and report on an 28  
intervention. The focus is on codified knowledge and the understanding that 29  
students acquire when working on design and construction projects. We expect 30  
that by designing a technical product with teacher help students will be stimu- 31  
lated to improve, first, their understanding of technical and scientific concepts 32  
and principles and, second, the rules and their interrelations as represented in 33  
models (see, for example, Kolodner et al., 2003). The models thus become tools 34  
in practical problem solving while, at the same time, providing a basis for con- 35  
necting practical use to theoretical knowledge. In contrast to our first case study, 36  
teacher guidance is more collaborative. The main issue in this research is whether 37  
co-constructing teacher guidance has a positive effect on codified knowledge and 38  
modelling. 39

## Theoretical background

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2  
3 Introducing students to certain sociocultural practices (e.g., workplace *as well as*  
4 mathematical practice) is best described as a process of legitimate peripheral par-  
5 ticipation (see Lave & Wenger, 1991). In such a context, learning may be seen as  
6 a process of qualitative change in activities, resulting in enhanced possibilities of  
7 sociocultural participation (Van Oers & Wardekker, 2000). Such enhancement  
8 also contributes to *enculturation* into a community of learners (Brown & Campi-  
9 one, 1994; Lemke, 2000; Rogoff, Matusov, & White, 1996). When learning takes  
10 place in a workplace setting, the agents involved (students and teacher) may be  
11 characterised as a *community of practice* (Lave & Wenger, 2005). In such commu-  
12 nities the participants share basic assumptions regarding the community's rules  
13 and purposes. As learners they are actively involved in meaning-making activities,  
14 as well as in problem solving with the aid of tools and artefacts, and communicat-  
15 ing with each other as well as with others outside the community.

16 Furthermore, sociocultural theory shows that in the accomplishment of ac-  
17 tivities new goals and needs may emerge which drive participants to construct  
18 or adopt new tools (See, for example, Kozulin et al., 2003; Saxe & Guberman,  
19 1998). Hence, by participating in communities, students may be compelled to  
20 aim for new goals that encourage them to adopt appropriate new practice-related  
21 tools, including concepts, symbols and models (Gravemeijer, Lehrer, Van Oers,  
22 & Verschaffel, 2002). In guiding the participation process teachers help their stu-  
23 dents understand the use and meaning of the concepts, symbols and models as  
24 tools in a range of similar practices. At the same time, the teachers themselves are  
25 participants in the same community and co-construction process as the students.  
26 It is important to remember that the teacher is not just a guide in this process of  
27 meaning making, but also a genuine participant (Van Oers, 2001). For example,  
28 the teacher may help students create a construction plan by asking questions  
29 referring to both domain specific rules for such a drawing and to the relevant  
30 mathematical concepts. In other words, teachers participate in the teams not only  
31 as guides but also as experts.

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

38 Although there are many different definitions of models, in this article we fol-  
39 low Van Oers (1988), who states that: "... a model can be described as any mate-

rial, 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 un-

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

10 The theoretical background sketched above leads to the following general  
11 hypothesis: *students who participate as model designers in a process of guided co-*  
12 *construction with an expert (teacher) and peers show better learning outcomes than*  
13 *students who learn to work with ready-made models provided by the teacher.*

14 The following three questions divide learning outcomes in terms of theoretical  
15 knowledge, test modelling and workshop modelling :

16 In a community of practice,

- 17 1. Do students in the experimental condition acquire more knowledge and a  
18 better understanding in mathematics and science?;
- 19 2. do students in the experimental condition develop a better understanding of  
20 the use of models?; and
- 21 3. do students in the experimental condition produce better models/drawings  
22 of their own products?

23

24

## Method

25

### 26 Research context & participants

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28 This study may be regarded as a design experiment (Barab & Squire, 2004; Col-  
29 lins, Joseph, & Bielaczyc, 2004; The design based research collective, 2003; Shavel-  
30 son, Phillips, Towne & Feuer, 2003). Based on case study findings (Van Schaik,  
31 Van Oers & Terwel, 2010a), we designed an educational programme for students  
32 in preparatory vocational education aimed at modelling. A pretest-posttest con-  
33 trol group design was used. The effects of the intervention were determined after  
34 controlling for initial differences, e.g., student characteristics and pre-knowledge.  
35 Due to the naturalistic nature of the design experiment not all possible variables  
36 were controlled for. For example, content of subject matter classes, group com-  
37 position, teacher experience and actual time spent on the assignment, as well as  
38 students' previous experience with these kinds of assignments could all affect the  
39 outcome. Consequently, in addition to test-scores, interviews and video observa-

tions were used to study the intervention process. As a characteristic design based 1  
research this study is also intended to further develop the concept of intervention. 2  
As such it may be regarded as a pilot study situated between the first case study 3  
and a larger experiment. 4

The participants in this study were a group of 15-year-old students (n=65) at 5  
two schools for preparatory vocational education. During the practice lessons 6  
students in both conditions worked in mixed groups of the two lowest learning 7  
tracks: basic and staff level.<sup>11</sup> We assigned both schools to the condition that best 8  
fitted their everyday practice, as explained above. This means that we adjusted 9  
the training and guidelines of the programme in this intervention to the teach- 10  
ing practice of the schools, which we identified during a visit and from inter- 11  
views with the teachers. The school in the experimental condition works with 12  
authentic assignments over the complete curriculum from first to fourth grade, 13  
including mathematics and science. Students at that school are used to initially 14  
solving problems themselves and are stimulated come up with their own models 15  
and solutions. Teachers guide them in the exploration process. Students finish 16  
their projects with an individual portfolio assessment by the teacher. The teacher's 17  
teaching methods in the experimental condition most resembled our assumptions 18  
on how to guide students to understand and use models in a co-constructive way. 19

The school in the control condition works with authentic assignments as well, but 20  
only in the practice lessons. Theoretical subjects (mathematics, science) are taught 21  
in the more traditional way of direct instruction. In addition, the practice teach- 22  
ers tend to *provide* the solutions to practical and theoretical problems. This means 23  
that when a problem is identified after identification by the teacher a solution is 24  
instantly provided. For example, when a student wishes to know how to determine 25  
the length of a piece of steel from a drawing, the teachers simply provides the for- 26  
mula. At the end of every assignment students are graded for their product and 27  
presentation. All the student has to do is work out the solution. In other words, 28  
the school's approach is consistent with the more traditional way of providing models. 29

## Intervention 30

The intervention started with a session with the teachers in which the aim of the 31  
intervention was explained and discussed. The teachers were provided with an 32  
educational instrument that consisted of a lesson plan and examples of problems 33  
34  
35

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11 In VMBO students are divided into four 'learning tracks.' They differ on the theo- 36  
retical level of the subject matter. The four levels are labelled 'basic level' (lowest 37  
theoretical level), 'staff level' (second theoretical level), 'mixed level' (intermediate 38  
level) and 'theoretical level' (highest theoretical level). 39

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

5 The differences between the conditions concerned the way modelling was in-  
6 troduced. In the control condition the models were to be ready-made and pro-  
7 vided as solutions to the students' problems; in the experimental condition the  
8 students were to be stimulated to design or (re) discover the models themselves.  
9 We collaborated with the teachers at every school on adjusting the educational  
10 programme to the teachers' needs and practices. However, the core of the inter-  
11 vention was maintained: guided co-construction versus providing. At each school  
12 the daily organisation and routines were different. The differences consisted, in  
13 particular, in the ways in which theoretical subjects were integrated into the prac-  
14 tical lessons and assignments. In addition, practical workshop lessons in voca-  
15 tional education were subject to continual change in that teams of teachers were  
16 often responsible for workshop guidance.

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

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

34

### 35 **Assignment**

36

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





Figure 4.1 First drawing of tricycle

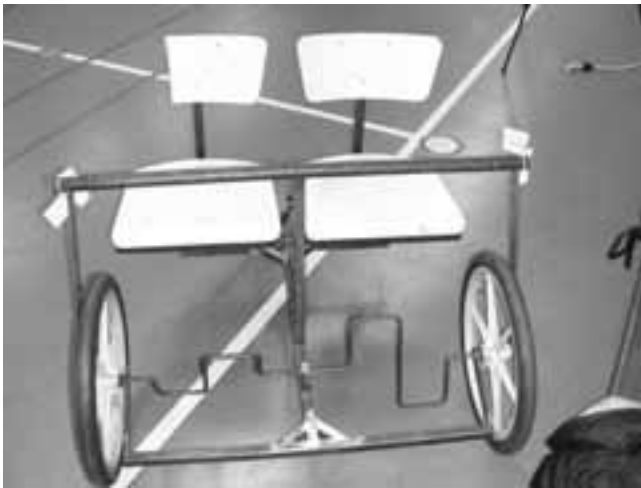


Figure 4.2 Picture of winner tricycle

### 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.

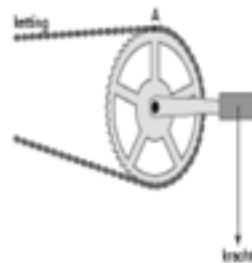


Figure 4.3 Sample test item on power transmission

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1 problems they were faced with while working on this ‘real-life’ assignment.

2 The student assignment was formulated as follows:

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

5 The assignment was placed in the context of a competition.

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

23

## 24 **Instruments and procedure**

25

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

32

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

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

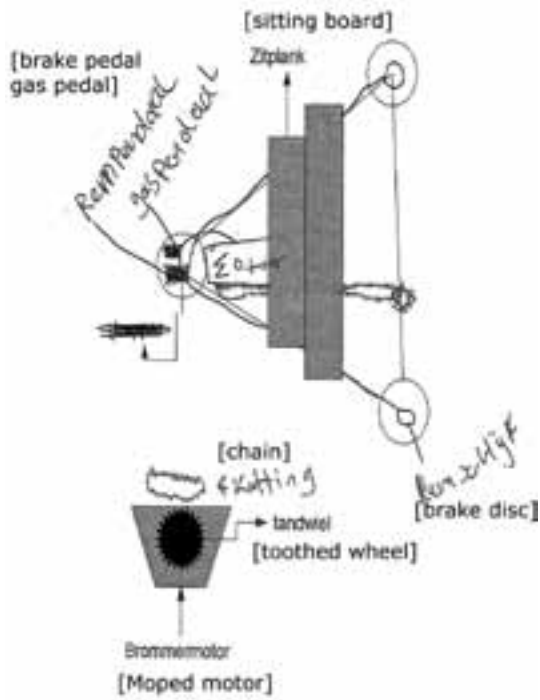


Figure 4.4 Sample test item on modelling

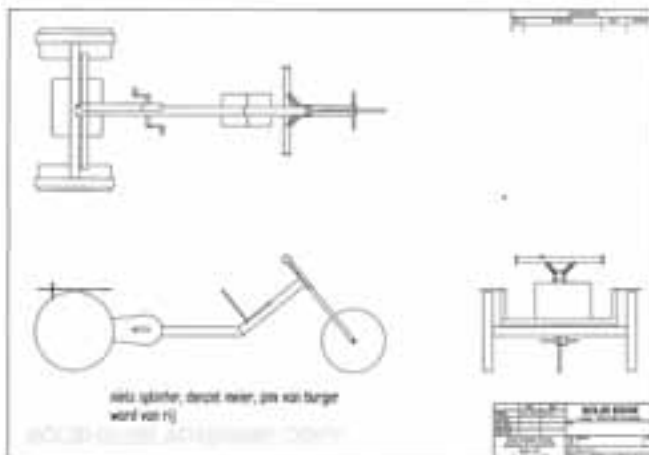


Figure 4.5 Final drawing of the product of a group in experimental condition

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

10

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

22 In order to follow the implementation of the programme participants, both  
23 teachers and students were interviewed during the intervention and afterwards.  
24 Lessons were observed using three cameras: two fixed cameras recorded the over-  
25 all classroom activities, while a hand-held camera recorded the interactions be-  
26 tween students and teachers close by.

27

28

## Results

29

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

35

36 The regression analyses are divided into three categories of outcomes, according  
37 to the three separate research questions (and their three dependent variables). We  
38 will first consider the learning outcome on knowledge; we will then address mod-  
39 elling 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)

1 models of the students as rated by modelling experts. As shown in table 4.2, we  
2 started with the main variables for each regression analysis. Only the statistically  
3 significant results are reported.

4

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

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

13

14 *Modelling as measured by the post-test in modelling*

15 With regard to post-modelling measured by the post-test the outcomes of the  
16 regression analyses also failed to confirm our hypotheses. However, a trend  
17 in the expected direction was found. Evaluated against initial differences on  
18 vocabulary and the pre-modelling test scores, the adjusted mean for the ex-  
19 perimental condition was 4.64 and 2.85 for the control condition. The adjusted  
20 mean knowledge gains, evaluated against the same covariates, were 1.30 and -  
21 0.64 respectively.

22

23 *Modelling of the product*

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

29

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

34

35 Looking at the coefficients, the interaction variable predicts the score negatively  
36 (table 4.4). This means that younger students benefit more from the experimen-  
37 tal condition than older students. Although our final hypothesis, namely that  
38 students in the experimental condition produce better drawings, could not be  
39 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<sup>3</sup>).

Model	R Square	Std Error of the estimate	R Square change	F Change	Sign. F Change
1	.55 <sup>1</sup>	10.50	.55	33.83	.000
2	.63 <sup>2</sup>	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

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

3

#### 4 **Enactment of the programme**

5

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

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

25 The main differences in enactment were time spent on the assignment and  
26 the way students finished the assignment, as concluded on the basis of the diary  
27 we kept as well as the actual school schedules. Regarding the time spent on the  
28 project, the experimental condition took fewer weeks than the control condi-  
29 tion (three weeks in all). The project for students in the experimental condition  
30 appeared more condensed. The project in the experimental condition was fitted  
31 more strictly into the school semester. Although the school in the control condi-  
32 tion took more time, this was not case for all students. After finishing the first  
33 semester students were regrouped and the two as yet unfinished tricycles were  
34 worked on by partly new groups. Moreover, according to the content log analyses  
35 for the practice classes, only a few students in the experimental condition worked  
36 on the tricycle during the practice lessons. Others continued working on other  
37 assignments. Apparently, the curriculum was more adaptive: students maintained  
38 their own speed and pace in their activities, whereas the other students in the  
39 control condition were to a much greater extent at the same point in their pro-



grammes and projects<sup>12</sup>. 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 I shows a transcription of two interactions during the corresponding specific ‘planning lesson’ in the experimental condition.

Excerpt I: experimental condition

I.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?’

I.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.

---

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.

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

4

5 Excerpt 2: control condition

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

9

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

25

26 The discussion continues and turns to transmission.

27

28 In semi-structured interviews, teachers reflected on their student guidance. From  
29 the interviews it was clear that the guiding process in both conditions was in line  
30 with what we had expected: in the control condition students were provided with  
31 the models, whereas in the experimental conditions students were guided in their  
32 process of exploration. Moreover, the models in the experimental condition were  
33 intended to be used as tools for thinking and exploration, while serving as (part  
34 of) a construction plan in the control condition. The teachers in both conditions  
35 agreed on the difficulties the project presented to the students. To get from the  
36 idea of a design to a usable design was hard for them: "... students have a hard  
37 time imagining during the work preparation what it [the product] will look like  
38 in reality" (experimental condition teacher). Or: "... [I] don't ask them to do the  
39 drawing themselves [the technical design model], because they are unable to"

(control condition teacher). As expected, the teachers differed in their responses 1  
to guidance. In the control condition the teacher made the technical drawings 2  
for the students: "... they learn by having it [technical drawing] provided." In the 3  
experimental condition the teacher wants to: "... expand the students 'thinking 4  
range,'" and, "guiding the students by showing and making them think [with 5  
models]. They learn through exploring." 6

## Conclusions & discussion 8

This study explores learning in the school workshop. In an intervention, students 10  
were selected to cooperatively design and build a tandem tricycle prototype. In 11  
two conditions teachers assisted them in solving problems, varying from the very 12  
practical to the theoretical. In the control condition models were provided as 13  
ready-made problem-solving tools. In the experimental condition models were 14  
collaboratively designed and reinvented by the students themselves under the ac- 15  
tive, co-constructive guidance of the teacher. 16

The research hypothesis was as follows: *students who participate as model designers 17  
in a process of guided co-construction with an expert (teacher) in the company of peers 18  
show better learning outcomes than students who learn to work with ready-made models 19  
provided by the teacher.* The following three specific research questions were formu- 20  
lated to compare results for a control group and an experimental group of students: 21

In a community of practice, 23

1. Do students in the experimental condition acquire more knowledge and bet- 24  
ter understanding of mathematics and science?; 25
2. do students in the experimental condition develop a better understanding of 26  
the use of models?; and 27
3. do students in the experimental condition produce better models/drawings 28  
of their own product? 29

The answer to first question is negative. Analyses show no difference between 31  
the conditions regarding knowledge of mathematics and science. The answer 32  
to the second question, regarding modelling, is tentatively affirmative, though 33  
only as a trend. Students under co-constructive guidance while working on 34  
authentic assignments have a better understanding of modelling. The outcomes 35  
concerning the third question are interesting. Although our hypothesis could 36  
not be confirmed, i.e. that students in the experimental condition produce 37  
better final product drawings, there was an interaction effect of age\*condition 38  
showing that younger students in the experimental condition produced better 39

1 scores on their final drawings than their counterparts in the control group.  
2 This effect might be related to the possibility that the older students had stayed  
3 down at some point during their school careers and thus were weaker students?  
4 With hindsight, this could mean that the experimental condition asked too  
5 much of those students.

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

25 Comparing the two conditions of programme enactment with regard to teach-  
26 ing methods, two main differences were observed.

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

34 Second, in the experimental condition the method of student assessment is  
35 shown to have been formative and intended to help students formulate new  
36 learning goals. By contrast, in the control condition the method of assessment  
37 was summative, aimed at grading the students on their product and presenta-  
38 tion. Furthermore, the role of models differed across the conditions as regards  
39 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, 1  
whereas in the experimental condition models were used to generate ideas and 2  
solutions. As MacDonald & Gustafson (2004) argue, this could mean that the 3  
creative use of drawings as open and multi-purpose tools may lead to a better 4  
understanding of those tools. 5

The outcomes of our study suggest that students in the experimental condition 6  
were better able to design models, both in the test, although not significantly, 7  
and in their own final product designs. The outcomes also show that knowl- 8  
edge acquisition was identical for both conditions. The teaching method in the 9  
experimental condition was more open, though less explicitly or continually fo- 10  
cused on modelling. This leads us to the conclusion that the co-constructively 11  
guided teaching explicitly focused on modelling, and that, consequently, the use 12  
of models as tools may have a positive effect on domain-specific student learning 13  
outcomes and students' understanding of modelling. 14

The results from the present study show the findings to be partly in line with 15  
other research on modelling. Van Dijk (2002) as well as Keijzer and Terwel (2003) 16  
found that teaching modelling co-constructively leads to better results in primary 17  
education. Doorman (2005) proposed that the application of guided reinvention 18  
in teaching modelling helps secondary school students achieve a better under- 19  
standing of graphing change. Others (Jurow, 2005; McArdle & Ackland, 2007; 20  
Van der Sanden & Teurlings, 2003) have argued that learning from practical ex- 21  
periences, project-based curricula, or authentic assignments improves transfer of 22  
knowledge. Guile and Young (2003) are more critical, arguing that participation 23  
in a 'community of practice' alone is not sufficient for knowledge acquisition, 24  
and that teachers should pay explicit attention to relating situated knowledge to 25  
more general knowledge. In the present intervention the programme was aimed 26  
at precisely that objective: moving from practical problems to mathematical and 27  
scientific modelling. 28

Further research will hopefully produce more qualitative examinations of the 29  
way models function as orientation and communication tools in the workshop, as 30  
well as how deeper understanding and knowledge acquisition depend on teacher 31  
guidance (with specific reference to providing versus co-construction). Put differ- 32  
ently, "How those tools are enacted in particular circumstances and activities is 33  
crucial" (Billett, 2001, p. 447). 34

Other notable suggestions from teacher interviews included remarks such as 35  
the following, "Students just don't come up with mathematics" and "[in the 36  
workshop] ... there is hardly any relation between theory and practice." In light 37  
of such remarks, our next programme design will pay more explicit attention to 38  
theory *as derived from practical problems*. 39

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

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

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5. 1  
2  
**Tools for learning in simulated workplaces:** 3  
4  
**results of an intervention in pre-vocational** 5  
6  
**education\*** 7

**Abstract** 8  
9

10  
Are models to be provided or designed in a process of guided co-construction? 11  
The present study examines the way in which groups of students gained knowl- 12  
edge in mathematics and science by designing and using models while working 13  
on technical assignments i.c. a tandem tricycle. Four schools and 87 students were 14  
8-10 weeks involved in a quasi-experimental design. After controlling for initial 15  
differences no differences in learning outcomes between the treatments could be 16  
found. The hypothesis had to be rejected. The schools with a tendency to better 17  
learning outcomes were schools with practice teachers who had a background in 18  
mathematics or science, a higher teacher-student ratio and students with higher 19  
scores on the pre-tests, than the other school. 20

21  
\* This chapter will be submitted as an article. 22

## Introduction

1

2

3 In this article we report on a study in pre-vocational education (vmbo)<sup>13</sup>, which  
4 examined the effects of an intervention aimed at enhancing students' codified  
5 knowledge in mathematics and science, as well as their understanding of model-  
6 ling, while in the process of designing and constructing a tricycle.

7 In many educational settings knowledge is codified in subject matter textbooks  
8 and other curriculum tools, most of it derived from academic disciplines (Eraut,  
9 2004). In vocational education, as well as in workplaces, codified knowledge is  
10 also available in bodies of rules (Guile & Young, 2003) and other specific tools,  
11 including, for example, machine manuals. Students in vocational education have  
12 to acquire this knowledge and at the same time become skilled in relation to their  
13 future professional practice. They are thus required to obtain competencies in  
14 order to be prepared for future demands, including codified knowledge as well  
15 as technical skills and attitudes (Cedefop, 2009; Commission of the European  
16 communities, 2008). However, relatively little research has been carried out into  
17 the type of learning environment in vocational education that is supposed to pro-  
18 mote this kind of learning (Koopman, Teune, & Beijgaard, in press).

19 The abbreviation vmbo denotes the system of preparatory vocational educa-  
20 tion at the secondary level in the Netherlands (Eurydice, 2008; Maes, 2004).  
21 Students between 12 and 16 years old follow a general curriculum with a vo-  
22 cational perspective. Work experience for students is organised both in school  
23 workplaces and extramural apprenticeships. The students' work experiences are  
24 used for developing generic skills and knowledge, as described in the generic  
25 model of work experience of Guile and Griffiths (2001). However, general subject  
26 matter is often separated from practical vocational skill teaching. In our research  
27 project we examine the quality of the learning outcomes in educational situa-  
28 tions in which subject matter theory and vocational skills are integrated, follow-  
29 ing a design-based research approach (Barab & Squire, 2004; Collins, Joseph, &  
30 Bielaczyc, 2004; Shavelson, Phillips, Towne, & Feuer, 2003; The design based  
31 research collective, 2003). An earlier case study showed that students can, given  
32 practical problems in the vocational workshops<sup>14</sup>, be guided towards a theoretical  
33 understanding of codified knowledge (Van Schaik, Van Oers, & Terwel, 2010a).  
34 The study in question demonstrated that a design and construction assignment  
35 may be potentially knowledge-rich. However, knowledge remained situated. The

36

37 <sup>13</sup> In this article pre-vocational education will be used to refer to the Dutch prepara-  
38 tory senior secondary education, vmbo.

39 <sup>14</sup> 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 1  
which we learned that explicit attention to models as tools resulted in a better 2  
understanding of models (Van Schaik, Van Oers, & Terwel, 2010b). 3

For the present study, the intervention was adjusted for four new schools, with 4  
a special focus on more explicit connections between product design and appro- 5  
priation of subject matter knowledge. Students were asked to design and build a 6  
prototype tandem tricycle. Teachers subsequently assisted the students in dealing 7  
with problems during the tricycle design and production stages. The students 8  
were encouraged to use or develop models to solve the problems they encoun- 9  
tered in working on this ‘real-life’ assignment. As we learned from the previous 10  
studies, stimulation in the practice workshop is insufficient for the reconstruction 11  
of subject matter knowledge and models on the basis of practical problems alone. 12  
In that light, we created a series of ‘prototype lessons’, during which students were 13  
guided to move from practical solutions and drawings to codified subject matter 14  
knowledge and models. 15

## Theory and practice in pre-vocational education 17

By way of an attempt to improve the relevance of knowledge and the effective- 19  
ness of knowledge transfer to the workplace, as is the case in other countries, a 20  
reform is taking place in Dutch pre-vocational schools (Guile & Young, 2003; 21  
Seezink & Van der Sanden, 2005). One of the proposed reforms envisions the 22  
teaching-learning process as an activity embodied in a simulation of real world 23  
practices. Students work on products for ‘real’ customers and in this context they 24  
are guided by teachers to acquire knowledge and skills. The basic assumption 25  
behind this approach is that learning of codified knowledge and vocational skills 26  
can be integrated into authentic workshop practices. The pedagogical approach 27  
can be characterised as what Tynjälä (2008, p. 144) calls “integrative pedagogics”. 28  
However, working on a (practical) problem is not enough to motivate students 29  
to learn (Guile & Young, 2003), and participating in real life situations is insuf- 30  
ficient to develop higher level expertise (Tynjälä, 2008). The challenge for schools 31  
is to design assignments that are meaningful for the students and relevant to their 32  
future jobs (Tuomi-Gröhm & Engeström, 2003; Volman, 2006). At the same 33  
time, assignments should also result in highly qualified learning outcomes that 34  
enable students to recontextualise their knowledge and skills from the classroom 35  
to the workplace. In short, teaching should support students in relating practi- 36  
cal problem solving to codified curriculum knowledge (Guile & Young, 2003; 37  
Van der Sanden, Terwel, & Vosniadou, 2000). From this perspective therefore, 38  
students need to be supported when solving real life problems with “conceptual 39

1 and pedagogical tools which makes it possible for them to integrate theoretical  
2 knowledge with their practical experiences.” (Tynjälä, 2008, p.145).

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

22

23

## Models as tools

24

25 In pre-vocational education students both design and construct real products. Dur-  
26 ing the design and construction processes problems arise that need to be solved.  
27 Models may be used to anticipate possible problems and their solutions. Although  
28 drawings and models are important in design technology and serve to commu-  
29 nicate and generate ideas, MacDonald & Gustafson (2004) claim that classroom  
30 emphasis is merely on their representational function. Students must be able to  
31 draw correctly, while their models, including assessment, are used for teacher diag-  
32 nostics only. If students’ classroom drawings were preceded by students’ orientation  
33 towards the problem situation and the exploration of ideas, modelling might de-  
34 velop into an active learning strategy which could help students gain deeper under-  
35 standing of problems and their possible solutions. This assumption is in line with  
36 the view of Tuomi-Gröhn and Engeström (2003). Rather than primarily having a  
37 diagnostic and explanatory function, models serve a dual purpose:

38 “On the one hand, the practitioners model the past and present contradictions  
39 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 1  
the other hand, the practitioners model also a future vision of their activity, in 2  
which they depict expansive solutions to the contradiction.” (Tuomi-Gröhn & 3  
Engeström, 2003, p. 32). 4

In this article models are defined, following Van Oers’s (1988), “... as any mate- 5  
rial, materialised (for example a graphical display) or mentally pictured construc- 6  
tion, built up from identifiable elements and relations, which structures the user’s 7  
action ...” (p.127). These models function as tools in orientation and communica- 8  
tion activities, in ways similar to those described by Tuomi-Gröhn & Engeström. 9  
For example, a model may allow the designer to calculate angles in a drawing in 10  
advance, so that steel may be sawn correctly in one single process, rather than by 11  
trial and error. Here the mathematical formula functions as an orientation tool. 12  
When, with regard to the present context, the drawing is used by students to 13  
negotiate the design of the tricycle with others, it also becomes a tool for commu- 14  
nication. Hence, orientation and communication are both functions of a model, 15  
which can consequently serve both at the same time. 16

## Disciplined perception 18

Modelling in the vocational education practice workshops can serve both stu- 20  
dents’ technical codified knowledge and the more general knowledge in subjects 21  
such as mathematics and science. When models as well as the accompanying 22  
planning solutions are used as means for orientation and communication in rela- 23  
tion to present and future problems students’ disciplined perception may develop 24  
(Stevens, 1998). This implies that students become familiar with the modes of 25  
thought that prevail in the discipline. In pre-vocational education the disciplines 26  
comprise both general curriculum subjects (derived from academic disciplines 27  
such as mathematics and science) and vocational disciplines, in our case those 28  
in the technical and technological domains. Students should be supported to “... 29  
gain a greater awareness and appreciation of the discourse repertoire ... and how 30  
it is used to create knowledge and to get things done” (Mercer, 2002, p. 147). 31  
They are therefore required to actively construct knowledge and information, 32  
applying the system of artefacts used in the practice of the discipline (cf. Beach, 33  
2007). However, according to Stevens and Hall, “disciplined” also implies that 34  
“learning to participate in disciplinary practices does not depend solely on ‘in- 35  
struction and exercise’...” (p.109). On the other hand, participation and working 36  
on authentic assignments alone is not sufficient either in attempts to acquire an 37  
understanding of modelling and codified knowledge. Obviously, for developing 38  
disciplined perception we need to avoid a strict opposition between unguided 39

1 discovery learning, minimally guided learning and direct instruction (e.g., see  
2 Kirschner, Sweller, & Clark, 2006), or between providing and generating teach-  
3 ing-strategies (Rosenshine, Meister, & Chapman, 1996).

4

5

## Guided co-construction

6

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

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

1 complexities involved in studying different school practices were also acknowl-  
2 edged (Goodlad, Klein, & Tye, 1979). We therefore follow Downing-Wilson,  
3 Lecusay & Cole (in press) in that, on the basis of joint activity with the teach-  
4 ers, the intervention was interpreted and changed by all parties involved, so  
5 that schools were assigned to the condition with which their current practice  
6 was most in line. Schools that tended to teach students theory and models in a  
7 providing fashion were assigned to the control condition. Schools that already  
8 had a teaching-learning practice that resembled guided co-construction were  
9 assigned to the experimental condition. Since we analysed the “design as imple-  
10 mented” (Ruthven, Laborde, Leach, & Tiberghien, 2009, p. 341) and adopted  
11 the “enactment perspective” to examine the implementation (Snyder, Bolin, &  
12 Zumwalt, 1992, p. 418), the intervention itself evolved as a result of our research  
13 interactions. Hence, details concerning the way the intervention actually devel-  
14 oped are reported in the results section.

15 The intervention consisted of a student assignment (see below) plus an educa-  
16 tional instrument for the teachers. The instrument was subsequently adjusted to  
17 the two conditions. It consisted of a series of embedded prototype lessons and  
18 examples of problems that students might encounter in design and construc-  
19 tion processes. The teachers were supposed to pay explicit attention to the way  
20 students’ situated knowledge was related to more general knowledge; moving  
21 from practical problems to modelling by the use of mathematical and scientific  
22 concepts. The prototype lessons were the instructional moments for reflection on  
23 the practical problems and their underlying principles.

24 The differences between the conditions concerned the way modelling was in-  
25 troduced. In the control condition the models were to be ready-made and pro-  
26 vided as solutions to students’ problems. In the experimental condition the stu-  
27 dents were stimulated to design or (re) construct the models collaboratively, while  
28 lessons or instructional moments were organised in situ.

29

## 30 **Participants**

31

32 87 15-year-old students from four schools participated in the present study.  
33 With the exception of School 2, where all students that participated were staff  
34 level, students worked in mixed groups of the two lowest learning tracks, basic  
35 and staff level, during the practice classes<sup>15</sup>. Schools were assigned to the condi-

36

37 <sup>15</sup> In VMBO students are divided among four ‘learning tracks’. They differ in the theo-  
38 retical level of the subject matter. The four levels are: ‘basic level’ (lowest theoretical  
39 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 Oldenhove*

Technical college Oldenhove 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

1 teacher guided the group, while subject matter teachers were rarely seen in the  
2 workplace. One prototype lesson out of five was taught without the assigned  
3 mathematics teacher present. The scores of two of the three pre-measures were  
4 below the sample mean.

5

#### 6 *Control School 4: Orthen Technical School*

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

16

#### 17 **Student assignment**

18

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

29

#### 30 **Teachers' educational instrument**

31

32 A teacher instrument was developed which consisted of a series of embedded pro-  
33 totype lessons and examples of problems that students might encounter during  
34 the design and construction processes. The instrument differed according to the  
35 way the students in the two conditions had to be guided. For the experimental  
36 condition the instrument consisted of a 'toolkit' with possible content for pro-  
37 totype lessons and templates for ad hoc lessons and instruction. The toolkit was  
38 intended as a reference base for the teachers. For the control condition the instru-  
39 ment 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.

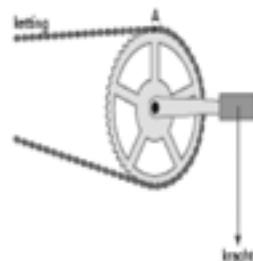


Figure 5.3 Power transmission about here

## 1 Instruments and procedure

2

3 To measure the students' pre-knowledge, nonverbal reasoning, and vocabulary, we  
4 administered several tests. First, knowledge and understanding of mathematics and  
5 science modelling was measured in a pre-test. The test consisted of 20 items. 17  
6 items were derived from national examinations for the testing of mathematical,  
7 scientific and technical knowledge. The three final test tasks were semi-structured  
8 drawing items, including ways of building a cart engine plus an accompanying  
9 visualisation task (see figure 5.4). The post-test was almost identical to the pre-test.  
10 The maximum score was 47 points. Cronbach's alphas were 0.75 for the pre-test and  
11 0.73 for the post-test. A sample national exam item is depicted in figure 5.3.

12

13 In addition we administered a national vocabulary test with a reported alpha of  
14 .89 (N=2200). The vocabulary test was administered by means of computers.  
15 Finally, Raven's Standard Progressive Matrices test was conducted to measure the  
16 students' non verbal reasoning and general factor of intelligence with a reported  
17 test-retest coefficient of .88 (J. Raven, J.C. Raven, & Court, 2000).

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

24

25

## Results

26

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

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

33

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

37

38 Correlations were computed to examine possible relations between the vari-  
39 ables. 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
<b>Overall</b>	<b>87</b>				
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
<b>Control condition</b>	<b>38</b>				
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
<b>Experimental condition</b>	<b>49</b>				
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

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

5

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

8

9 The differences between all schools on the post-test were measured by means of  
10 ANOVA:  $F(3, 69) = 18.31$ ,  $p = .00$ . A one-way analysis of covariance (ANCOVA) was  
11 subsequently conducted to examine the way the covariates were related to the  
12 independent variable school. The dependent variable constituted the score on  
13 the post-test and the covariates the score on the pre-test the vocabulary test and  
14 the SPM. A preliminary analysis to evaluate the homogeneity-of-slopes assump-  
15 tion indicated that the relationship between the covariates and the dependent  
16 variable did not differ significantly as a function of the independent variable,  
17  $F(3,44) = .38$ ,  $F(3,44) = 1.95$  and  $F(3,44) = .38$ ,  $MSE = 23.31$ , with respectively  $p = 0.77$ ,  
18  $p = .13$ ,  $p = .77$  and partial  $\eta^2 = 0.25$ ,  $\eta^2 = .12$  and  $\eta^2 = 0.25$ . ANCOVA was significant,  
19  $F(3,53) = 1.07$ ,  $MSE = 23.91$ ,  $p < 0.01$ . The strength of relationship between the schools  
20 and the dependent variable was medium as assessed by partial  $\eta^2$  with the school  
21 factor accounting for 6 per cent of the variance of the dependent variable, with  
22 the pre-test scores, vocabulary and SPM held constant.

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

33

34 No significant difference was found between the two conditions on post-test  
35 scores and no school from either one of the conditions differed significantly from  
36 the others. Our hypothesis that the experimental condition would outperform  
37 the control condition must therefore be rejected. Moreover, it should be noted  
38 that School 4 students scored very low on vocabulary ( $M = 57.82$ ) and that School  
39 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
<b>Experimental group</b>	<b>49</b>				
<b>School 1</b>	<b>33</b>				
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
<b>School 2</b>	<b>16</b>				
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
<b>Control group</b>	<b>38</b>				
<b>School 3</b>	<b>23</b>				
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
<b>School 4</b>	<b>15</b>				
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			

1 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.

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

10

## 11 **Analyses of intervention as implemented**

12

13 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.

17 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.

24 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.

38 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
<b>Experimental group</b>				
School 1	69.03	38.83	13.81	18.50
School 2	75.00	47.50	26.93	21.15
<b>Control group</b>				
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
<b>School 1</b>	3:33	1:11
<b>School 2</b>	4:16	1:4
<b>School 3</b>	1:23*	1:23
<b>School 4</b>	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.

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

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

13

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

27

28

## Conclusion

29

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



ing a real product themselves, do students, under co-constructive guidance, gain 1  
codified knowledge in mathematics and science and a better understanding of 2  
modelling? 3

From the perspective of our theoretical framework it was expected that when 4  
guided in a co-constructive way, plus the use of models as creative thinking tools, 5  
students would perform better on a post-knowledge and modelling test than stu- 6  
dents who were provided with preformatted models and knowledge. This expect- 7  
ation produced the following hypothesis: students in the experimental condi- 8  
tion outperform their counterparts in the control condition on the scores of the 9  
post-test. 10

Data analysis led to the conclusion that our hypothesis must be rejected. Stu- 11  
dents in the experimental condition did not outperform their counterparts in the 12  
control condition. Nor, after controlling for initial differences, were any differ- 13  
ences between the schools found. Although the ‘best’ performing school was in 14  
the control condition, condition was not the factor that explained the difference 15  
on the post-test. A comparison between the schools did not result in a significant 16  
difference between schools. Schools 2 and 4 had the highest adjusted scores on 17  
the post-test. 18

Analyses of the design implementation produced clues that might explain the 19  
small differences in the results. The two schools (2 and 4) that showed the highest 20  
scores on the post-test were schools with practice teachers who had a background 21  
in mathematics or science, and a higher teacher-student ratio than the other 22  
schools. In addition, the students at the schools in question used CAD software to 23  
draw their constructions models, while the implemented intervention was closest 24  
to the intended intervention. The most plausible explanation here is that a high 25  
teacher-student ratio plus the presence of a subject matter teacher in the work- 26  
shop resulted in the higher scores. 27

## Discussion 28

We agree with Gresalfi (2009) that collaborative practices and the meaning-creat- 31  
ing opportunities they afford are important for learning. However, Dutch pre-vo- 32  
cational education differs from other systems in that it has a dual focus, directed 33  
towards vocational knowledge and skills as well as on general codified knowl- 34  
edge derived from the academic disciplines. According to this view, collaboration 35  
on authentic assignments alone is insufficient to integrate skills and disciplinary 36  
knowledge. The missing collaborative factor is the teacher, who is required to 37  
support students in relating practical problem solving to codified curriculum 38  
knowledge (Guile & Young, 2003; Van der Sanden, Terwel, & Vosniadou, 2000). 39

1 At all four schools in our intervention students collaborated on tricycle design  
2 and construction. At two schools (school 2 and 4) where teachers had the op-  
3 portunity to intensively guide the students from situated problems to codified  
4 knowledge students scored slightly better on the post-test than their counterparts  
5 at the other schools. On the post-test the scores on average were between 38 and  
6 43 per cent, students at School 2 and 4 however scored above 50 per cent. Since  
7 the test consisted of items of previous final exams, the students at these schools  
8 may have been already at the required final exam level, whereas the students at  
9 the other schools were not. The fact that workplace teachers at the schools in  
10 question had backgrounds in the relevant academic disciplines might be taken to  
11 suggest that teachers in those classrooms used conceptual and pedagogical tools  
12 to integrate subject matter theory (Tynjälä, 2008). Also, students at the two best  
13 performing schools used CAD software for their drawings. This software forces the  
14 students to model like designers, in ways similar to normal practice in their future  
15 occupations. In other words, with the support of academically trained teachers,  
16 the students' disciplined perception may have been enhanced, in the following  
17 two ways (Stevens & Hall, 1998). First, students assumed the role of workers in  
18 their discipline (vocation). Second, they learned to see the connection between  
19 practice and theory: they not only practised their vocational skills in the work-  
20 place, but were, in addition, trained to use the models as tools for problem solv-  
21 ing both in vocational practice and in the academic disciplines that were reflected  
22 in the curriculum subjects. Further research will have to focus on the micro level  
23 to examine the enhancing effect of CAD software use on disciplined perception.  
24 In addition, it needs to be noted that students at School 2 and 4 scored relatively  
25 high on the SPM-test, which is a rather perceptual test for non-verbal reasoning,  
26 although statistically this variable was not significant.

27 Given that we only found minor statistical differences, further study of the com-  
28 plex environment will have to be considered. Strict control of the conditions proved  
29 impossible, while a fidelity approach would have been counterproductive in this  
30 rather loosely organised schooling domain. As a consequence the implementation  
31 of the design differed considerably among the schools. Since groups of students and  
32 teams of teachers are especially unstable in pre-vocational education, a larger sam-  
33 ple could only partly solve that problem. We also know from our logs, observations  
34 and interviews that adaptation to the local school context does not ensure imple-  
35 mentation of the intervention as intended. The concept of mutual appropriation  
36 may therefore be the correct one to gain insights into the dynamics of interventions  
37 in (pre-vocational) education, with on one side the researcher(s) and on the other  
38 the teacher(s) (Downing-Wilson, Lecusay & Cole, in press).

39 Further research might, by means of micro-analyses, confirm the teacher char-

acteristics 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

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

24  
25 \* This chapter will be submitted as an article.

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## 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)<sup>16</sup> 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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<sup>16</sup> 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.

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

10 In addition, as the product is finished, the steps in the design process can be  
11 traced back by looking at the earlier sketches or models used in the design and  
12 construction process. From this reiterative reflection process understanding and  
13 codified knowledge may emerge by which the design process is made explicit and  
14 the final product transparent. Put differently, the blackbox of a technical product  
15 opens up and a *knowledge-rich* situation is created by students and teachers alike.  
16 The elements, concepts, insights and procedures can be used not only to repro-  
17 duce the same construction but also to inspire a new design, as for example the  
18 transmission principles and gearwheels for a clock or a bicycle. Ultimately, it is  
19 insight into the basic structure that enables recontextualisation in new situations.  
20 In other words, it is not so much construction but reconstruction that is the key  
21 to understanding and to the appropriation of codified curriculum knowledge: 'It  
22 is continuous reconstruction, moving from the child's present experience out into  
23 that represented by the organized bodies of truth that we call studies' (Dewey,  
24 1981;1902, p. 472).

25 Once models are used as a means of orientation and communication in relation  
26 to present and future problems and planning solutions to such problems, stu-  
27 dents may develop *disciplined perception* (Stevens & Hall, 1998). This means that  
28 students become familiar with various modes of understanding a discipline or a  
29 particular practice, moving from perception to conceptual and strategic think-  
30 ing. In vocational education the relevant disciplines are academic, in the form  
31 of general curriculum subjects (derived from academic disciplines such as math-  
32 ematics and science) and vocational, in our case the technical and technological  
33 domains. Students should be supported to '... gain a greater awareness and appre-  
34 ciation of the discourse repertoire [of the domain] ... and how it is used to create  
35 knowledge and to get things done' (Mercer, 2002, p.147). Consequently, they  
36 need to actively construct knowledge through the practical system of disciplinary  
37 artefacts (cf. Beach, 2007). Hence, 'disciplined' also implies that '... learning to  
38 participate in disciplinary practices does not depend solely on 'instruction and  
39 exercise ...'(Stevens & Hall, 1998, p.109). Students need explicit support in the

reconstruction of disciplinary concepts, models and methods. Since learning to 1  
participate in practical contexts cannot depend on instruction, and given that 2  
students need to actively construct knowledge, we need to overcome the distinc- 3  
tion between unguided discovery learning and direct instruction (Kirschner et al., 4  
2006); between a providing strategy and a generating teaching strategy (Rosen- 5  
shine et al., 1996). The strategy of *guided co-construction* could be a 'third way' to 6  
resolve this dichotomy (Mercer, 1995; Van Oers, 2007; Hardman, 2008). In such 7  
an approach the role of the teacher is crucial to connect the practical problems to 8  
codified disciplinary knowledge. 9

We conceive of models '... as any material, materialised (for example a graphical 10  
display) or mentally pictured construction, built up from identifiable elements 11  
and relations, which structures the user's action ...' (Van Oers, 1988, p.127). The 12  
models function as tools in orientation and communication activities. For exam- 13  
ple, a model may allow the designer to calculate angles in a drawing in advance, 14  
so that steel can be sawn correctly in one single process rather than by trial and 15  
error. Here the mathematical formula functions as an orientation tool. When the 16  
drawing is subsequently used by students to negotiate about the design, it also 17  
becomes a tool for communication. Hence, orientation and communication are 18  
both model functions, with the model serving both at the same time. Profes- 19  
sional designers in the vocational discipline use models and drawings as thinking 20  
tools to generate ideas and to communicate proposals (MacDonald & Gustafson, 21  
2004). When students learn to use models in the same way as professionals the 22  
models serve this dual function of orientation and communication. 23

We needed to look at the classroom micro level in order to find the key deter- 24  
minants that might lead to a deeper understanding of codified knowledge and 25  
modelling in the school workshops. For this purpose we used the data of the latest 26  
experimental intervention to conduct a qualitative analysis. We aimed, first, to 27  
find out in general the precise ways in which designs were implemented at every 28  
school. Our next goal was to establish how the modelling developed microge- 29  
netically within a process of tandem tricycle construction, and whether it was 30  
effective in joining experience and general knowledge, as codified in the general 31  
curriculum. The following two questions arose in the process: 32

1. What was the actual teaching/learning practice in the schools and how did 33  
the schools differ, especially in the way the models functioned as tools in the 34  
design process? 35
2. Was the teaching/learning practice aimed at designing and understanding 36  
related to the disciplines, both academic and vocational? 37

38

39

## 1                    Models as tools in the practical design process

2  
3 In design education, drawings and models often only serve to plan or repre-  
4 sent the product to be constructed. By contrast, in professional design processes  
5 models and drawings also function as thinking tools to generate ideas and to  
6 communicate proposals (MacDonald & Gustafson, 2004). This is in line with  
7 our view that models are tools for orientation and communication. We follow  
8 Tuomi-Gröhn and Engeström (2003) who state that models can be used, first,  
9 to reflect on past processes and subsequently to negotiate a possible direction for  
10 their future activity. For example, in vocational education a draft model of a tri-  
11 cycle is a reflection of student efforts to design a product that is to be constructed.  
12 It enables the makers to use the model to show where their design process had  
13 taken them up to the point of examination and to discuss or explain their solu-  
14 tions to others. Moreover, the model functions as a plan for future action: it *is* the  
15 construction plan.

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

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



290). Hence modelling should not become a detached subtask to be finished 1  
before students are allowed to proceed to construction. Only when modelling is 2  
integrated as a functional strategy in the complete design process, from draft to 3  
finished product, can its role and function be truly understood. 4

These processes of collaboration and negotiation to develop a disciplined per- 5  
ception and a deeper understanding are neither unguided nor minimally guid- 6  
ed processes. The teaching strategy is better described as *guided co-construction*. 7  
Guiding in a co-constructive way means helping students to collaboratively re- 8  
construct models and subject matter knowledge through an ongoing and recip- 9  
rocal discursive process, focused on the solution of task-related problems. It is the 10  
teacher's role to '... maintain connections between the curriculum-based goals 11  
of activity and a learner's existing knowledge, capabilities and motivations' (Mer- 12  
cer, 2002, p. 143). Research has shown that the instructional strategy of guided 13  
co-construction may lead to better understanding of mathematics and modelling 14  
than a strategy based on simply providing ready made models as solutions to 15  
problems (Doorman, 2005; Terwel et al., 2009; Van Dijk et al., 2003). Mercer 16  
(2002) gives the following summary of the characteristics of teachers who were 17  
successful in supporting pupils in their development of mathematical problem 18  
solving and reading comprehension. Such teachers use questions 'not just to 19  
test knowledge, but also to guide the development' (Mercer, 2002, p. 144). They 20  
also taught more than just subject content. They helped students understand 21  
the problem-solving strategies and make sense of their experiences. Finally, 'they 22  
treated learning as a social, communicative process' (Mercer, 2002, p.144). All of 23  
these characteristics are elements of what we call guided co-construction. In con- 24  
trast to a 'providing' form of teaching in which knowledge, concepts and models 25  
are presented as ready made solutions, guided co-construction may lead to a bet- 26  
ter understanding of the process of modelling itself. 27

The schools in the study were originally assigned to two conditions. In the ex- 28  
perimental condition students were guided in a co-constructive way, while in the 29  
control condition guidance was more traditional and the models were provided 30  
as ready-made solutions. As mentioned earlier, we will not use the conditions as 31  
a variable in this article. The schools in each of the conditions adapted the in- 32  
tended design of the curriculum project into somewhat of a unique educational 33  
configuration (see below). In the following qualitative analyses all schools will 34  
be regarded as separate cases. We looked for ways in which models function in 35  
classroom practice and how teachers guided the design process. The main focus 36  
of analysis was to find the key determinants of a pedagogy that supports students' 37  
modelling and thus the use of models as tools, irrespective of the conditions the 38  
students were assigned to. 39

## Method

1  
2  
3 This multiple case study (Yin ,2006) is part of a design-based research project  
4 (Cobb et al., 2003). After the three previous project studies we are currently  
5 focusing on classroom micro-processes between teachers and students. The  
6 project's overall methodological approach can be placed in the tradition of  
7 formative interventions (Engeström, 2009). The concept of mutual appropria-  
8 tion is probably an appropriate concept to understand the dynamics of inter-  
9 ventions in (vocational) education (Downing-Wilson et al., in press). Our in-  
10 tended design was adjusted together with the teachers to their local conditions,  
11 helping us to understand the school context and helping the team of teachers  
12 to understand our aims. The unit of analysis in this study is the subgroup, with  
13 teachers present in the classroom.

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

### 23 24 **Participants and setting**

25  
26 87 students at four schools participated in the study. They worked on the tricycle  
27 assignment in subgroups of three, four, or five (all male, mean age 16.06 years).  
28 As measured on the pre-tests, the significant differences were on vocabulary, SPM  
29 and pre-knowledge. At all schools the teachers were responsible as a team for a  
30 larger group of students, which often included the participating students. In total  
31 12 teachers participated. The students worked most of the time in a workshop  
32 setting, where computers and technical equipment were available. Some schools  
33 used a separate classroom for instruction and/or computer designing (see below).  
34 As already mentioned, the four schools were initially divided into two conditions  
35 according to their daily teaching and learning practice. Since the way in which  
36 the school adapted the intended curriculum design was part of our analyses, de-  
37 tailed descriptions on how the intervention was enacted are reported in the results  
38 section.

39

<b>Schools</b>	1
	2
<i>School 1: Peter Willems College</i>	3
This school had 33 students in 11 groups of three working on the project. Students	4
worked in a large central workplace area with a computer room in the middle and	5
two classrooms on the side, where they went for theoretical instruction. Some-	6
times the computers were used for information searching. Most of the time a sin-	7
gle senior teacher guided and graded the students. Other teachers and classroom	8
assistants helped students with practical problems.	9
	10
<i>School 2: Technical College Oldenhove</i>	11
At School 2 four groups of four students out of a class of 24 chose to work on	12
the assignment (two other groups were working on other authentic assignments).	13
Students worked in two spaces: one, their ‘own’, with computers and various	14
forms of technical equipment, and one for the metal work (welding). A team	15
of four teachers, subject matter as well as practice teachers, guided the students.	16
	17
<i>School 3: Prince of Orange College</i>	18
At School 3 five groups of four or five, 23 students in all, worked on the as-	19
signment. Students worked in a large open workplace with technical equip-	20
ment and computers available. The subject classes were held in a different part	21
of the school building. The workshop space was one of the corners of a very	22
large ‘practice square’ with all vocations having their own corner and a central	23
teacher’s office in the middle. Computers were available, as well two smaller	24
instruction rooms.	25
	26
<i>School 4: Orthen Technical School</i>	27
This school had 15 students working in five groups of three. The workshop space	28
was large and had recently been refurbished. Computers and a separate instruc-	29
tion space were available. Students were guided by both two practical teachers	30
and one teacher who taught prototype lessons. The latter was also a practical	31
welding teacher for the project students. The teacher in question had formerly	32
been a teacher of mathematics and physics. Computers with 2D-CAD software	33
were used for the drawings.	34
	35
<b>Materials</b>	36
	37
<i>Assignment</i>	38
For the student the assignment was the following: <i>Design and construct a prototype</i>	39

1 *of a tandem tricycle for children aged 4-7 in such a way that the children have to*  
2 *cooperate.*

3 The assignment was placed in the context of a competition among peer stu-  
4 dents. One of the requirements was the production of a model of the final prod-  
5 uct as it was actually was constructed. This could be the construction plan as  
6 continuously developed, or a 'reverse engineered' model.

7 The students had to design and construct the tandem tricycle in a ten-week  
8 period, during which they worked at least two hours a day in the workshop  
9 setting and in open classrooms where computers were available. In both spaces  
10 teachers were available for questions and guidance. The design process was re-  
11 flected on during workshop hours or in lessons or sessions separate from the  
12 workshop and the construction process (the prototype lessons). During work-  
13 shop practice mainly practical problems were encountered, which were most  
14 of the time directly solved or redirected to separate lessons. During the latter  
15 periods teachers offered guidance in problem solving, using the students' own  
16 designs as well as the relevant subject matter in science and mathematics. Mod-  
17 els were used either in a providing way or in a co-constructive way; respectively  
18 supporting students with ready made models as solution to problems, or guid-  
19 ing them in constructing their own models. For the students the process started  
20 with an introduction by the researchers explaining the purpose of the assign-  
21 ment, namely the construction of a prototype to win a competition. During  
22 the following first week the students started designing (see figure 6.1 for an ex-  
23 ample) and moved on to construction in the weeks following. The competition  
24 ended in the first instance with the selection of the two best prototypes at each  
25 school, followed by a final adjudication with a jury deciding on the winning  
26 construction. (figure 6.2).

27

28 *Guiding instrument for the teachers*

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

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

39

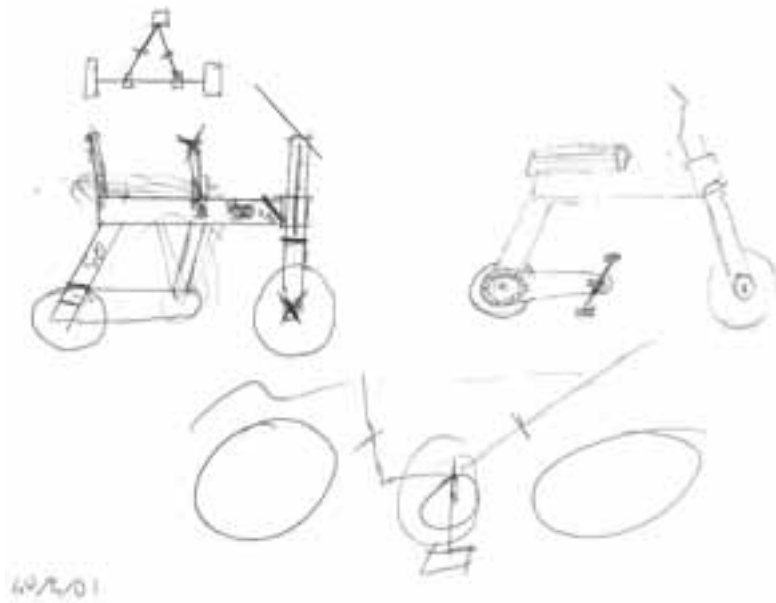


Figure 6.1: first sketch of tricycle of School 1 about here



Figure 6.2: picture of winning tricycle about here

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## 1 Instruments and procedures

2

3 The main source of data for the present analyses were the video data consisting of  
4 classroom observations and interviews. Video was collected using a three camera  
5 approach, with two fixed cameras recording opposite angles of the whole classroom  
6 and one hand-held camera recording the interactions and activities from closer by  
7 (see Van Schaik, 2009). The video data were loaded into computer software (Noldus,  
8 2009) and the video streams from each camera were viewed simultaneously.

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

13

## 14 Analyses

15

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

26

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

39 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)	1
Category 1: Initial sketches	2
Clues	3
A sketch is made at the beginning of a project	4
The sketch indicates the pupil's initial thoughts/key ideas about the project.	5
The sketch is exploratory and conceptual rather than representational.	6
The sketch is made quickly and spontaneously.	7
The sketch includes images and words.	8
Category 2: Elaborate and refining drawings	9
Clues	10
A series of freehand and hard-line drawings are made during the project.	11
The drawings are shared with other members of the design team.	12
The drawings transform the ideas expressed in the initial sketch.	13
The drawings elaborate, refine, expand, and develop the pupil's initial ideas.	14
The drawings show increasing accuracy and detail, including dimensionally.	15
Category 3: Final and presentation drawings	16
Clues	17
The drawing is made at the end of the project.	18
The drawing is a recognizable representation of the finished product.	19
The drawing can be used by those outside the design process as a guide to making.	20
The drawing is hard-line, finished, precise, and detailed.	21
The drawing is labeled and measured.	22

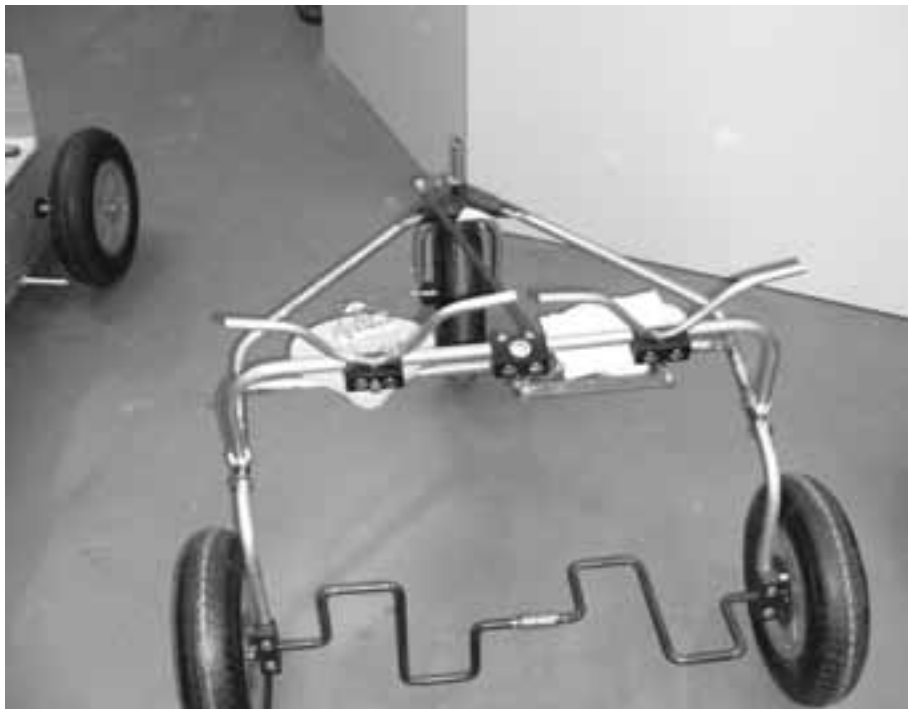


Figure 6.3 Tandem tricycle with two front wheels from students in School 1

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

17

18

## Results

19

20 In the qualitative school analyses we discuss whether and how the student draw-  
21 ings and models function as tools during the design and construction process-  
22 es. In the across-school comparison we compare the qualitative results with the  
23 quantitative results from the previous study.

24 For every school we describe how the intervention was enacted in general  
25 (within-school enactment). That is, how designing, constructing and, with regard  
26 to the control schools, the prototype lessons were taught. Next, the role of models  
27 and teacher guidance is discussed in the within-school enactment. Sample inter-  
28 actions on the role of models and teacher guidance will be described. The over-  
29 all pattern of each school's enactment is summarised first. In the across-school  
30 comparison we discuss how this description relates to the learning outcomes, the  
31 models and the students' tricycle drawings.

32

### 33 Within-school enactment

34

35 *School 1.*

36 Overall Pattern: *Teachers in the practice workspace helped the students with practi-*  
37 *cal problems, without explicitly referring to mathematics, science or other codified*  
38 *knowledge.*

39



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	00:47:00	1			
Week 4							P-lesson	00:32:30	0			
Week 5										Practice (drawing)	01:08:13	6
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	00:57:07	5
Week 8										P-lesson	00:31:21	1
Week 9												
Week 10				Practice	01:25:48	3				Practice	02:13:39	0
Week 11	Presentations(10)	00:49:00	2	Presentations(3)	00:52:05	3						
Later												
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)*

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

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

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

18

19 Excerpt 1.1

20 Teacher [Whilst drawing]

21 The fixed part will be connected like this, right?

22 Then you'll have to make a little block for the axle to go through.

23 You need to connect it with two bolts

24 You see?

25 You can then put the axle in and move it around.

26 Later with the students and teacher by the frame:

27 Teacher: You see what I mean?

28 It can be welded onto this and the axle can run through it.

29

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

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

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

reverse-engineered model. 1  
Only two interactions on models were found in week six. However, week three 2  
produced 10 (out of a total of 13 interactions over all observations, see Table 2). From 3  
that week's observation we learned that the students had to finish their drawings 4  
and plans in week three to be allowed to continue with construction. From several 5  
interactions between teachers and students it was clear that the drawings required 6  
dimensions, scales and views from three angles.. As one teacher said: 'Draw the 7  
dimensions, ..., that's what I need. Then you are finished with the drawing'. The 8  
only reference to mathematics was heard during this week: 9

Excerpt 1.2 11

Teacher [Standing at a work bench, whilst drawing and pointing to a 12  
scale model for the student] 13  
... if this is 10 cm. larger, it will be a little more than 10 cm. 14  
larger, according to Pythagoras, but never mind that. 15  
... 16  
Teacher: You see that? 17  
Student Yes, about there? 18  
Teacher Then you can start with [constructing] the frame. 19  
Student Only that one then, then we can start with the frame. Cool. 20  
21

The reference to Pythagoras does not amount to anything more than mentioning 22  
the existence of the rule. The dialogue continues on how to get the drawing fixed 23  
in order to proceed with the construction. 24

Overall, at School 1 models needed to be elaborated and moderately refined 25  
before students could proceed with the actual construction of the tandem tricycle. 26  
Once they were into the construction process the models disappeared (after 27  
week three) and only the teacher used drawings to help students with the practical 28  
issues. The drawings referred to in the interactions were therefore either initial 29  
sketches or elaborated drawings. 30

During peer presentations, students briefly reflected on their processes, while 31  
showing pictures and the final product. Only two of the ten groups showed their 32  
design drawings, others only mentioned them briefly, if at all. Hardly any ques- 33  
tions were raised during the presentations. 34

Two pairs of students were interviewed. In the interviews the students explained 35  
that they sometimes worked on similar projects. The difference with the regular 36  
projects was that regular projects come from books and sheets and are short-term. 37  
In excerpt 1.3 one student explains the difference between regular assignments 38  
and the tricycle assignment. 39

1 Excerpt 1.3

2 Student The [tricycle] assignment is more fun. You are working on a  
3 product.

4 When you are working only on electricity, you are reluctant  
5 when you fail over and over again.

6 [with the tricycle assignment] you can't do anything wrong.

7 ...

8 You can choose how and what to construct.

9

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

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

20

21 School 2.

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

25

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

37 In week six of their project models and drawings were still lying around in the  
38 classroom. All together we counted three interactions on the models involved.

39 In one interaction, a student explains to his group how they should proceed

with welding. Another subgroup first discusses construction issues behind the 1  
 computer screen, with a paper drawing on the desk. Next, the group splits up 2  
 and three of the members go to the metal classrooms, where they continue their 3  
 construction. The student responsible for the drawing follows them later to bring 4  
 the drawing. At the end of the lesson he draws on a piece of wood, explaining to 5  
 the researcher that he is making a drawing so as to determine the angles for the 6  
 pieces of steel that have to be sawn. He is using wood because the other students 7  
 need the paper version of the drawing for their tasks. When the teacher suggests 8  
 that he could calculate rather than measure the angles the student asks the teacher 9  
 for help (see excerpt 2.1), in the following exchange: 10

Excerpt 2.1 11

Teacher	I should not have to explain this	13
	You have to go to the mathematics teacher for that	14
Student	He is not available	15
Teacher	Why don't you do it in AutoCAD	16
Student	AutoCAD does not work, otherwise I would have done it	17
	already.	18
	Student walks out of the classroom and comes back. He is still	19
	busy measuring the angle of the pieces to be sawn.	20
Student	Sir, I measured the angle and it was ..[inaudible]	21
Teacher	That's what I thought, because it was 60/30/30 [pointing at the	22
	angles of three of the complementary corners that make up the	23
	square]	24
Student	Right, then you should have said so	25
Teacher	Certainly not	26
	The teacher takes the measuring tool from the table with the	27
	pieces of steel on it	28
Teacher	When viewed from this angle, I see 60/30/30	29
Student	Right	30
Teacher	No, this is what you have to learn to see.	31
	The teacher goes on explaining tricks on how to see, and guess	32
	the angle.	33

In the other observations students were busy creating AUTOCAD or 3D models 35  
 of their designs. Teachers assisted them and helped determine the expected 36  
 tricycle dimensions or calculate proportions and scale. In the last observation 37  
 before the presentations, three elaborated models featured in interactions. The 38  
 presentation models in the student presentations could be categorised as final 39

1 and presentation drawings.

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

13

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

22

23 Excerpt 2.2

24 Student This time the dimensions were a problem.

25 We only saw that when the seats were being constructed.

26 We corrected that in the drawing.

27

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

34

35 Excerpt 2.3

36 Teacher [A student] shows his problem to the mathematics teacher,  
37 comes up with a solution, and returns [to the Comtech class-  
38 room]

39 ...

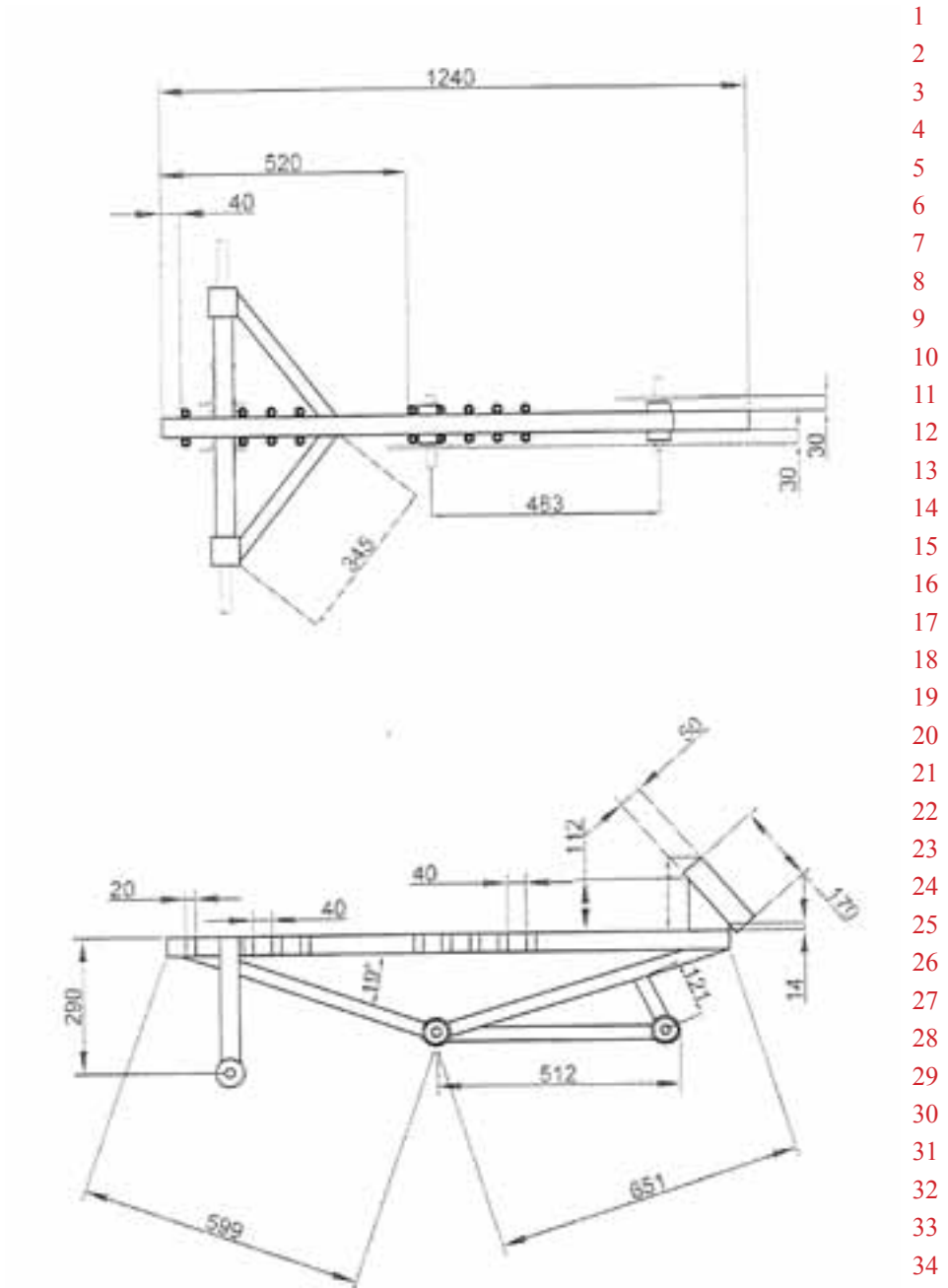


Figure 6.4 Final drawing by School 2 students

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

3

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

9

10 *School 3.*

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

14

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

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

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

31

32 Excerpt 3.1

33 Teacher           So, if you want that, you'll have to connect the handle bars so that  
34 they are connected and both turn when one of the kids is steering.

35 Student           Really?

36                   [They walk to a metal model of a crane]

37 Teacher           As you can see, when the handle bars are here and here, the  
38 complete construction moves and the bicycle turns.

39



The example above is typical of the way students in the workshop were guided 1  
mainly in their practical constructions. Practical tips and solutions were provided 2  
and skills were demonstrated. As already mentioned, hardly any interactions on 3  
models were found, neither in the other observations nor in the prototype lesson. 4  
Only in week nine were students found behind the computer reverse-engineering 5  
their construction drawings. At that stage drawings were still initial sketches. 6

In an interview with two students during the project, they first pointed out 7  
that the difference between the tricycle assignment and the usual assignments 8  
was the time available. Normally an assignment took two to three weeks. They 9  
also confirmed our observations that no assistance was provided by mathemat- 10  
ics or physics teachers. The only help offered was in the workshop during prac- 11  
tice hours. 12

In the interview the teacher confirmed that only a few subgroups created final 13  
drawings. He stopped the practice, because he thought it was not 'moving in the 14  
right direction'. With regard to student learning he did not think mathematical 15  
understanding had improved during the project. 16

Excerpt 3.2 17

Teacher Focusing more attention on mathematics and physics by means 18  
of the project did not work out. Although there was some draw- 19  
ing done in AutoCAD ... 20  
the drawings were not usable ... without dimensions and so on. 21  
Those are between their [students'] ears. 22  
23

At this school, especially during the construction stage, we did not find any 24  
examples of the explicit use of concepts, models, mathematics or physics. There was 25  
hardly any connection with theory as expressed in curriculum subjects. The pro- 26  
totype lesson could be characterised as an introduction to the practical problems 27  
of tricycle construction and the only drawings used as reference were an internet 28  
and the initial computer sketch. 29  
30

School 4. 31

Overall pattern: *By drawing and questioning, the teacher relates the practical issue of 32  
construction to the theoretical concepts of transmission, speed and ratio, as well as to 33  
other practical examples.* 34  
35

In comparison to the other schools the students appeared to spend more time on 36  
designing. In project week seven they were still found behind computers trying 37  
to find the optimal transmission or wheels. Prototype lessons (three out of five) 38  
39

1 were taught separately to the whole group. The teacher at this school took on a  
2 role different from his usual one as a welding teacher. Since his background was  
3 in mathematics and science he took the lead in the project. He taught three of the  
4 five advised prototype lessons and guided the students during the construction  
5 together with one other teacher.

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

19

20 Excerpt 4.1

21 Teacher           What is this length [pointing to the drawing]  
22                       400?  
23                       40 cm.  
24                       And this one? Have you switched that off [a function in the CAD  
25                       software]  
26                       Or, you could make this 45 too and this 55  
27                       ...  
28                       [students bend the tube and go back to the drawing to check  
29                       how to saw off tube ends]  
30 Teacher           Which part should be 40? Take your drawing.  
31                       Here you put 40, but is that 40 on the top or...  
32 Student           That's on the top.

33

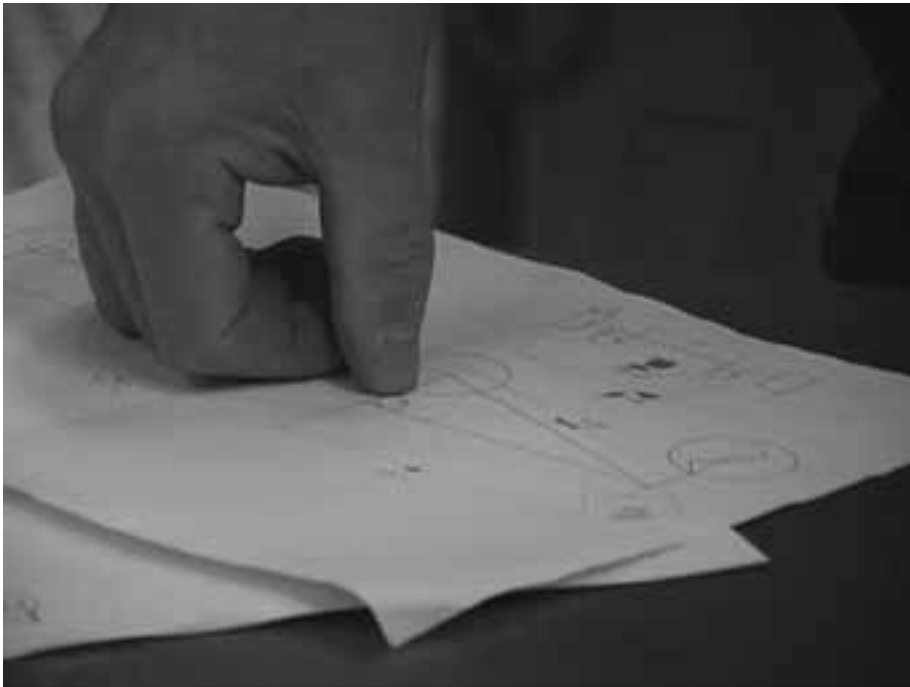
34 The interaction continues on how to saw off tube parts.

35

36 The teacher uses the drawing to help the students with their problem of bending  
37 and sawing the frame tubes. He refers to the drawing and not only tries to find out  
38 what the students' plans are, but also notes that the drawing is not clear to him. In  
39 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*

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

7

8 Excerpt 4.2

9 Teacher Do I need a small [gearwheel] in front and large one at the rear?  
10 Or the other way around?

11 A student responds

12 Teacher Say small in front, large at the rear, then what happens?

13 ...

14 Let's put some figures on it

15 ...

16 Now, what is the number of revolutions for the front wheel per  
17 minute?

18 How fast will the tricycle move?

19 First I need a calculation, a formula.

20 ...

21 [Students respond and arrive at the point where they need to  
22 know the circumference of the wheel]

23 That's maths: how do I calculate the circumference of a circle?

24 [The instruction continues with the speed of the tricycle and the  
25 number of lathe revolutions ]

26

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

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

The teacher confirmed the students' statements. He said that the only theory 1  
students usually get in practice is reading construction drawings. On the tricycle 2  
assignment he thought the students learned mathematics and physics, "because 3  
they realise its useful." 4

At School 4 the elaborated drawings remained present during the construction 5  
stage of the project, with teachers referring to them when they helped students 6  
with practical problems, such as bending a tube to the correct angle. The observed 7  
prototype lesson focused explicitly on the mathematics and physics concepts be- 8  
hind the transmission of a tandem, though the teacher provided the models in 9  
a readymade fashion. Working in groups and designing themselves were new 10  
activities for the students. 11

### Across-school comparison 12

In the across-school comparison we are interested in how the overall process at all 15  
schools can be characterised and to what extent schools differ in their enactments. 16  
We eventually relate this to the learning outcomes as measured by the tests. 17

First, week six observations confirm the experience from earlier studies to the 18  
effect that at that stage in the process at three of the four schools the students 19  
are in fact in between designing and construction. The video data show that the 20  
frames of most tricycles are finished and students are connecting the other parts 21  
to it. At Schools 1 and 3 wheels are already connected and students are playing 22  
with the tricycles. Except for one school (School 3), drawings and models are still 23  
present in the workplace. At Schools 2 and 4 the models are explicitly referred to 24  
and used as tools for communication and orientation. At School 2 this reference 25  
is used not only to solve the practical problem but also as an example to refer to 26  
the academic discipline of mathematics: how to calculate and estimate angles (see 27  
excerpt 2.1). The orientation goes beyond the actual construction towards the 28  
formulation of a strategy. 29

Secondly, it seems that the construction is now the main object of the students' 30  
activities, from week six onwards. All interactions are about what to do how in 31  
construction. The teachers mostly have to help with practical problems, such as 32  
where to find tools or how to adjust the machines. At School 1 this is already the 33  
case in week three, when construction drawings and plans have to be finished. 34

Table 6.3 shows that at School 2 all subgroups (four) had final presentation 35  
drawings. Although some students at School 1 use their drawings during presen- 36  
tation, they do not reflect on the drawing itself or use it as a tool to explain their 37  
process. At no other school were final drawings found. At School 3 only initial 38  
sketches were observed. Apparently, the design process continued until the end 39

1 of the project only at School 2, while drawings were also used as tools for com-  
2 munication.

3

4 In characterising the four schools we observe that two schools stand out. At  
5 School 2 the drawings and models are not only used and refined until the end but  
6 they are also used to explicitly refer to mathematics. In addition, during the dis-  
7 cussion on the place of mathematics in drawings, the teacher revealed something  
8 of his approach to teaching in his student guidance (see Excerpt 2.1). At School  
9 4 the drawings remain present during construction and are used by teachers and  
10 students as tools to communicate on practical problems. The teacher used models  
11 to explain mathematics and physics related to the tricycle assignment during the  
12 prototype lesson. At the two other schools (1 and 3) the models were all but absent  
13 or disappeared during the process, and hardly any explicit attention is given to  
14 mathematics or scientific concepts.

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

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## Conclusion & discussion

35

36 In this paper we argue in favour of modelling as a core activity during practical  
37 classes to improve students' understanding, and to effect an integration between  
38 practical work and general curriculum subject matter. Qualitative and quantita-  
39 tive 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

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

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

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

14

15 From analyses of the within-school enactment and from across-school compari-  
16 sons it is clear that two schools stand out in the way models are used in their  
17 practice workshops. Each school could be characterised by a unique, overall inter-  
18 action pattern. In the present section we will elaborate - and reflect on - these pat-  
19 terns in the light of our theoretical assumptions on modelling. At Schools 2 and 4  
20 the models remained visible and continued to be used until the end of the proc-  
21 ess, whereas at Schools 1 and 3 the models to all intents and purposes disappeared  
22 once the actual construction of the tandem tricycle had begun. The conclusion  
23 is that the use of models at Schools 2 and 4 resembles the practice of professional  
24 designers more accurately than at Schools 1 and 3 (MacDonald & Gustafson,  
25 2004). Moreover, at Schools 2 and 4 far more interactions on models were found  
26 in the observations. Teachers and students used their models as tools for orienta-  
27 tion and communication. The first was observed for example when students at  
28 School 4 discussed whether or not to design a tandem that could also be disman-  
29 tled into two separate bicycles (see p.129). At School 2 students communicated  
30 by means of models when they tried to find solutions to practical problems, for  
31 example in determining the correct angle for sawing off tube ends (e.g. excerpt  
32 2.1). They updated their drawings when the design changed during the construc-  
33 tion process. This updating could be viewed as a way to establish their collective  
34 memory and use the model as a tool for communication at later moments in  
35 time, with themselves or their peers (see Excerpt 2.2). Although interactions on  
36 models were also observed at School 1 (not at School 3), the teacher at that school  
37 regarded the students' models as tasks to be finished before actual construction  
38 could start. Hence, the students' drawings were checked on certain points, after  
39 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 1  
at School 2 and 4, as opposed to School 1 and 3, the drawings were actual tools in 2  
the design process and remained visible until the end of the project. 3

With regard to students' understanding of the disciplines, we are led to the 4  
conclusion that at School 2 the vocational discipline of (technical) designing was 5  
the main goal. Students continued designing and created a final presentation 6  
model on which they reflected during a presentation to peers and teachers. At 7  
School 4 the academic disciplines of mathematics and physics were given explicit 8  
attention during the process, with the teacher teaching the appropriate content 9  
during the prototype lessons. In addition, the quantitative data show that School 10  
4 had the highest adjusted means on the post-test which measured the relevant 11  
knowledge, whereas School 2 scored highest on all pre- and postmeasures. At the 12  
two other schools there were few signs of attention to academic disciplines during 13  
workshop practice. The teaching/learning strategies seemed mainly aimed at vo- 14  
cational skills. In sum, the formation of disciplined perception (Stevens & Hall, 15  
1998) was only supported at Schools 2 and 4. 16

In addition to the support for disciplined perception, the drawing of construc- 17  
tion models as a means of constructing a tricycle at Schools 2 and 4 was not 18  
merely a goal in itself during the design and construction process. Teachers at 19  
both schools explicitly pointed out the function of models to the students. Some- 20  
times models were used to find solutions to practical problems (e.g. the correct 21  
way of bending a tube to the right angle), while at other times the teacher used 22  
models to refer to mathematical rules (e.g. calculating or estimating angles in a 23  
drawing). We conclude therefore that at those schools modelling was integrated 24  
into the overall design process, from draft to finished product. As a result the role 25  
and function of modelling was well understood by the students. 26

The teaching strategy at School 2 resembled best that of guided co-construc- 27  
tion. The students collaboratively reconstructed models through an ongoing and 28  
reciprocally discursive process, focused on the solution of task-related problems. 29  
However the knowledge codified in the subject curriculum was only indirectly 30  
referred to. At School 4 on other hand, codified knowledge was taught in a pro- 31  
viding way, resembling direct instruction. 32

Since it is the teacher's role to '... maintain connections between the curric- 33  
ulum-based goals of activity and a learner's existing knowledge, capabilities and 34  
motivations' (Mercer, 2002, p.143), the question remains how codified knowledge 35  
is best instilled. Consequently we suggest that discussions about unguided or 36  
minimally guided or direct instruction (Kirschner et al., 2006) should be aban- 37  
doned in favour of finding out what teachers actually do, when, where and how. 38  
In our view, then, further research is required to explore teaching/learning strate- 39

1 gies that incorporate the practices of schools such as Schools 2 and 4.

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

8 Even on the limited basis of the present data the conclusion is warranted that  
9 modelling is potentially capable of enriching practical assignments with theoreti-  
10 cal concepts from mathematics and science. Such enrichment is, in turn, capable  
11 of creating disciplined perceptions. The two schools which produced the most  
12 models observed in interactions were also the ones that showed the highest scores,  
13 while the difference between the two schools consisted in the conditions we ini-  
14 tially created. We conclude that modelling as a core activity in vocational educa-  
15 tion could be the key to integrating theory into the workshop.

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## General conclusion & discussion 2 3

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This final chapter brings together for a comprehensive reflection the findings and 5  
conclusions of all the separate studies. In the first section below the research ques- 6  
tions are repeated. In the next section those questions are addressed by providing 7  
a chronological summary of the findings of each study. We will end with some 8  
remarks on educational theory and practice and propose some suggestions for 9  
further research. 10

The overall research question of this design-based project was the following: 11  
do students, who participate as model designers in a process of guided co-con- 12  
struction with an expert (teacher) and peers, show better learning outcomes than 13  
students who learn to work with ready-made models provided by the teacher? 14  
The general, working hypothesis is that collaboratively learning to design and use 15  
models in vocational education has positive effects on learning outcomes, com- 16  
pared to providing ready-made models to the students. The basic idea underlying 17  
the hypothesis is that students will develop knowledge and skills in modelling 18  
along with codified knowledge in mathematics and science as a result of con- 19  
structive involvement and dialogic inquiry under teacher guidance. In all three 20  
interventions the students were to design and construct a technical product in the 21  
form of a tandem tricycle (in the first case study a bicycle racing game was the sec- 22  
ond product). The overall research project was divided into three interventions: 23  
a case study, and two experiments in a pre-test post-test control group design. 24  
These interventions resulted in four studies (see below). 25

### Summary of the results: a narrative of the 26 design-based research 27 28

#### Case study (Study 1) 29 30

31  
The first questions we addressed in Study 1 were: (1) What teaching/learning 32  
processes occur in a simulated workplace using the concept of a knowledge-rich 33  
workplace? (2) What is the role of models and modelling in the teaching/learning 34  
processes? 35

In a case study (chapter 3; Van Schaik, Van Oers, & Terwel, 2010a) we explored 36  
the implementation of two assignments and the subsequent teacher guidance at 37  
one school and tested whether or not the learning environments became knowl- 38  
edge-rich (Guile & Young, 2003) as a result. Knowledge-rich workplaces are as- 39

1 summed to engage students in meaningful activities and at the same time promote  
2 subject matter learning (including mathematics, see Kent, Noss, Guile, Hoyles,  
3 & Bakker, 2007). In other words, the learning environment has the potential for  
4 students to acquire knowledge that is codified or disciplinary. The results showed  
5 that designing a tandem tricycle did, in fact, create opportunities for teaching  
6 students codified knowledge and modelling. The teachers, however, tended to  
7 simply provide ready-made models while for the students the knowledge involved  
8 remained situated. That is, as solutions to problems, mathematical and scientific  
9 concepts and models tended to be bound to the (practical) situation in which  
10 they were constructed. Although the assignment itself was potentially knowl-  
11 edge-rich from the teachers' perspective, students could not relate the provided  
12 problem solving models to more general codified knowledge. Our assumption is  
13 that if the models had been designed by the students under teacher guidance, the  
14 role of models as tools would have become clear and the relation between theory  
15 and practice might have become more transparent in the process.

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

24

## 25 **First experiment (Study 2)**

26

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

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

37

38 The first experiment was an intervention at two schools following the case study.  
39 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 modeling? 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

1 the determinants that might explain differences in learning outcome at school  
2 level. First of all, in Study 4, the goal was to examine precisely how the design was  
3 enacted at each school. Next, we aimed to establish how the activity of model-  
4 ling developed with the process of constructing a tandem tricycle. Moreover, we  
5 sought to find out if modelling actually brought together practical experiences  
6 and the codified theories of the general curriculum. Hence, the two questions  
7 that arose in this last study were the following: (1) What was the actual teaching/  
8 learning practice at the schools and how did the schools differ, especially in the  
9 way the models functioned as tools in the design process of the students? (2) Was  
10 the teaching/learning practice aimed at designing and understanding related to  
11 disciplines, both academic and vocational? We conducted qualitative micro anal-  
12 yses in order to find out how models functioned in classroom practice and how  
13 teachers guided the design process. The conclusion was that the use of models  
14 at two schools resembled the practice of professional designers more than at the  
15 other schools (MacDonald & Gustafson, 2004). Teachers and students used their  
16 models as tools for orientation and communication, which engaged the students  
17 more authentically in the reality of the workplace. As a result, the formation of  
18 their disciplined perception (Stevens & Hall, 1998) was presumably better sup-  
19 ported at these schools (chapter 6; Van Schaik, Van Oers & Terwel, submitted b).  
20 All in all, the question whether or not students show better learning outcomes  
21 when they are the model designers in knowledge-rich simulated workplaces in  
22 a process of guided-co-construction remains unresolved. Based on the tests in  
23 the two experiments, the conclusion is that there is hardly or no difference in  
24 learning outcomes compared to students who had ready-made models provided.  
25 However, two findings lead us to believe that guided-co-construction might im-  
26 prove the students' understanding of modelling and codified knowledge. First,  
27 the students in the experimental condition in the first experiment produced bet-  
28 ter models. This may have been due to the fact that the teachers used their models  
29 as communication and orientation tools (chapter 4). Secondly, at two schools in  
30 the final experiment more interactions on models were found, while models were  
31 part of the process for a longer time (chapter 5). Moreover, the models were in  
32 a more finalised state. We therefore concluded that the students' design process  
33 at those schools resembled that of professional designers more than that of the  
34 students at the other schools. Our impression was that disciplined perception is  
35 better supported at schools where designing is integrated into the activities of the  
36 simulated workplaces. As a consequence students' understanding and knowledge  
37 are enhanced (see chapter 6). This leads to our overall conclusion that the use of  
38 models as tools for communication and orientation in product-oriented voca-  
39 tional 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 & Beijgaard, 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

1 at which teachers were able to link students' practical problems to theory, concurs  
2 with the results in Van de Pol et al. (in press), in which observed teachers showed  
3 few examples of guidance that were contingent on student capabilities.

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

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

23 With regard to the content of modelling teaching in vocational education, the  
24 focus of teacher guidance should be on the process of designing. Since we learned  
25 that those schools performed best at which the enacted curriculum project resem-  
26 bled the practice of professional designers, the suggestion is that when students  
27 act as designers they learn better how to use models and reach acceptable levels  
28 of knowledge. Moreover, models that are used as tools for orientation and com-  
29 munication and utilised in combination with teacher guidance, can support stu-  
30 dent understanding as well as enhance the knowledge codified in academic and  
31 vocational disciplines.

32 It follows from the above considerations that teacher guidance is crucial. Two  
33 main characteristics can be formulated from our studies. First, teachers who  
34 are capable of explicitly integrating theory and practice through their academic  
35 background guided students to better (use of) models. Teams of teachers should  
36 therefore be composed in such a way that at least one of the teachers has an  
37 academic background and is able to connect that to the workplace. This way  
38 students can be guided towards concepts, rules and principles of academic and  
39 vocational disciplines by working on practical assignments. Secondly, as we saw,



when students work on their own design and draw models themselves their own 1  
models are more elaborate, and they perform better on modelling tests. Hence, 2  
teacher guidance should have a student's own design as its starting point. 3

Finally, for the assignment it proved important that it was 'real' and complex. 4  
Students were motivated to work on products that could be used as real products. 5  
Although the assignment in the two experiments had no clients, the prototype 6  
competition was real enough. In addition, to promote understanding and codi- 7  
fied knowledge, assignments need to be complex, though not too difficult. The 8  
tricycle assignment had the right balance in this respect. It was complex enough 9  
to connect practical problems to academic as well as vocational disciplines, such 10  
as are, for example, manifested in the concepts of transmission and the principles 11  
of designing and modelling. At the same time the assignment proved not too dif- 12  
ficult, since most students were able to finish the product. 13

In light of the above, the discussion about providing versus guided co-construc- 14  
tion can be taken a step further by specifying in greater detail what teachers really 15  
do, where, when, and finally how their activities are related to learning outcomes. 16  
In other words, the proposed focus for future research consists in the further 17  
elaboration of the different forms of guidance (by instruction, discussion, etc.) 18  
in workplace contexts and how such forms could support students' development 19  
towards expertise in the vocational practice. More detailed studies are required 20  
into the development of disciplined perception and into ways in which such de- 21  
velopment could be stimulated in workplace settings. 22

Further research should also explore a teaching/learning strategy that incor- 23  
porates actual school practice. In ideal practical situations students design and 24  
construct complex 'real' products, guided by teachers who are able to connect 25  
practical problems to disciplinary theory, while the students' own designs form 26  
the basis for guidance. Only approximations to such situations could explain 27  
what guided co-constructing means for teaching and learning in general, with 28  
specific reference to (pre)vocational education. 29

At this stage the empirical relevance of these practical implications to educational 31  
theory needs to be addressed. First of all, in the course of the three interventions 32  
we developed the concept of a knowledge-rich learning environment in voca- 33  
tional education. We started by stating that it should be an environment in which 34  
students acquire more than just practical skills. Codified knowledge should also 35  
be imparted in such an environment. Our final impression is that if the concepts 36  
of both Guile and Young (2003) and Stevens and Hall (1998) are connected, the 37  
learning environment has the potential for students to acquire codified or disci- 38  
plinary knowledge. Furthermore, the results of the two experiments have led to 39

1 an improved understanding of how models work as tools in vocational education  
2 and that the use of such tools may result in acceptable knowledge levels (i.e.  
3 scores above 50 per cent on posttests). Our view of models as tools for orientation  
4 and communication was enriched by the way models work in a design process  
5 in school practice (MacDonalds & Gustafson, 2004). Finally, we now have ad-  
6 ditional proof that guided co-construction as a teaching-learning strategy works  
7 in pre-vocational education. Furthermore, the nature of what constitutes relevant  
8 guidance has been further elaborated (see for example the suggestions above).  
9 While working on real products VMBO students need the type of guidance that  
10 leads them from their own designs and models to the knowledge codified in voca-  
11 tional and academic disciplines. Such guidance must explicitly connect theory to  
12 practical problems. Only in that way will students be able to learn to recontextu-  
13 alise their practical knowledge within the system of codified disciplinary knowl-  
14 edge. Such recontextualisation will improve their practical skills as well as their  
15 theoretical knowledge. In short, our theory of modelling in vocational education  
16 has now been connected to VMBO practice.

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# Nederlandstalige Samenvatting 1

## Samen modellen construeren als ‘tools’ in de beroepspraktijk 2 Leren in een kennisrijke omgeving 3

Iets meer dan de helft van de leerlingen in de klassen drie en vier van het voortge- 6  
zet onderwijs volgt een vmbo opleiding. Dat staat niet in verhouding tot de mate 7  
waarin deze sector voorkomt in wetenschappelijke literatuur. Langzaam maar ze- 8  
ker verschijnen de eerste artikelen en rapportages over onderzoek in het vmbo 9  
(zie bijvoorbeeld: Boersma, ten Dam, Monique Volman, & Wardekker, 2009; 10  
Koopman, Teune, P., & Beijaard, in press.; Seezink, 2009; Van Schaik, Van Oers, 11  
& Terwel, in press; Van de Pol, Monique Volman, & Beishuizen, in press). Dit 12  
proefschrift is een volgende toevoeging aan die reeks en beschrijft een onderzoek 13  
dat tussen 2006 en 2009 op zeven scholen is uitgevoerd. De hoofdvraag van het 14  
gehele onderzoeksproject is: zijn de leeruitkomsten van leerlingen, die deelnemen 15  
als ontwerpers in een proces van guided co-construction met peers en experts 16  
(leraren), beter dan de leeruitkomsten van leerlingen die leren te werken met kant 17  
en klare modellen, aangereikt door de leraar? 18

Vanaf begin in 1999 was het vmbo bedoeld als een onderwijsinnovatie (Van der 19  
Waals, 2009). Van oorsprong was het beroepsonderwijs vooral gericht op vaardig- 20  
heden. In de tachtiger jaren van de vorige eeuw kwam bij de voorgangers van het 21  
vmbo de nadruk meer op theorie te liggen. Geen van beide benaderingen voldeed 22  
volledig. De eerstgenoemde praktische benadering hielp de leerlingen niet opti- 23  
maal zich breed te ontwikkelen. De tweede benadering was vaak te moeilijk en 24  
leidde tot betekenisloos mechanisch leren. De laatste jaren zijn in het vmbo de 25  
leraren op zoek naar een balans tussen theorie en praktijk. Van der Waals (2009) 26  
noemt dit een stille revolutie. 27

Een belangrijke vernieuwing in het vmbo betreft de ontwikkeling van geïnte- 28  
greerde leeromgevingen. Praktijkvakken en vaktheorie worden niet langer afzon- 29  
derlijk aan de orde gesteld. Ook komt het voor dat avo-vakken zoals wiskunde, 30  
Engels en Nederlands geïntegreerd worden in de praktijkopdracht. Leraren en 31  
leerlingen worden gezien als (mede-) ontwerpers van geïntegreerde leeromgevin- 32  
gen (vgl. ook Van der Sanden, Streumer, Doornekamp, Hoogenberg, & Teur- 33  
lings, 2003). De opdracht waaraan de leerlingen in dit onderzoeksproject werkten 34  
was het ontwerpen en bouwen van een tandemdriewieler. De opdracht moest 35  
kennisrijk zijn en authentiek. Dat wil zeggen dat de leerlingen geïntegreerd the- 36  
orie en vaardigheden konden leren. Authentiek betekent dat de leerlingen de bete- 37  
kenis van hun handelen inzagen en dat het werken aan de opdracht representatief 38  
is voor hun toekomstig mogelijk beroep (Volman, 2006). 39

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

5

6

## Theoretisch kader

7

8 De gedachte achter het authentiek leren in geïntegreerde leeromgevingen is dat  
9 gecodificeerde kennis tegelijk met beroepsvaardigheden geleerd kan worden door  
10 te werken aan ‘echte’ opdrachten. In het vmbo gebeurt dat vooral op de scho-  
11 len zelf in werkpleksimulaties (Van der Sanden, Streumer, Doornekamp, Hoog-  
12 enberg, & Teurlings, 2003). Het is echter niet vanzelfsprekend dat door werk-  
13 plekleren ook gecodificeerde kennis verworven wordt (Nijhof, Nieuwenhuis &  
14 Terwel, 2006; Tynjälä, 2008). Het onderwijs zou de studenten moeten begeleiden  
15 van praktische problemen naar gecodificeerde kennis van de avo vakken (Guile  
16 & Young, 2003; Van der Sanden, Terwel, & Vosniadou, 2000). Daarvoor zou-  
17 den studenten geholpen zijn met “conceptuele en didactische instrumenten die  
18 het mogelijk maken om theoretische kennis te integreren met hun praktische  
19 ervaringen” (Tynjälä, 2008, p.145. Guile & Young, 2003, p. 73) noemen zo een  
20 werkplek een ‘kennisrijke werkplek’. Kennisrijke werkplekken kunnen studenten  
21 betrekken in betekenisvolle activiteiten en tegelijk kennisontwikkeling stimule-  
22 ren (zoals wiskunde bij Kent, Noss, Guile, Hoyles, & Bakker, 2007). Modellen  
23 kunnen op die kennisrijke werkplekken functioneren als conceptueel en didac-  
24 tisch instrument.

25

### 26 Modellen als ‘tools’

27

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

## Guided co-construction

1

2

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).

11

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.

16

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).

29

30

## Methode

31

32

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 we-

39

1 derzijdse erkenning ('mutual appropriation') van lerarenteams en onderzoekers  
2 (Downing-Wilson, Lecusay, & Cole, in druk). De leraren leerden de bedoelingen  
3 en theorie daarachter van de onderzoekers kennen, terwijl de onderzoekers leer-  
4 den begrijpen wat er wel en niet kon op de scholen en hoe de leraren omgingen  
5 met de interventie. In alle fasen van het onderzoek is video gebruikt voor observa-  
6 ties en interviews. De videodata hebben het onderzoek helpen ontwikkelen. Ten  
7 eerste door vanuit de video-analyse het onderwijsontwerp kon worden aangepast.  
8 Ten tweede omdat ook de methode door middel van de video in beeld kwam en  
9 daardoor zowel beter afgestemd als gevalideerd kon worden. Ten derde omdat  
10 met terugwerkende kracht in de video de ontwikkeling te zien was van het de  
11 theorie: het perspectief, letterlijk en figuurlijk, veranderde in de loop der tijd.

12

13

## Case study

14

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

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

31

32

## Eerste experiment

33

34 In de tweede studie is de opdracht uitgewerkt voor twee condities op twee scho-  
35 len. In de experimentele conditie ontwerpen de leerlingen de modellen die nodig  
36 zijn zelf in samenwerking met elkaar en onder begeleiding van de docent. Dit  
37 proces van 'guided co-construction' helpt leerlingen de modellen beter te begrij-  
38 pen, omdat ze doelgericht ermee aan de slag zijn (Terwel, 2009). In de controle  
39 conditie worden de modellen als kant en klare oplossingen aangeboden. Het

bleek dat de twee groepen in traditionele kennis niet verschilden. De leerlingen 1  
in de experimentele conditie maakten wel betere eindtekeningen van de driewie- 2  
lers. Uit analyse van de kwalitatieve data bleek dat in de experimentele conditie 3  
de modellen inderdaad functioneerden als tools in het ontwerp- en bouwproces, 4  
maar dat in de controle conditie de modellen langer zichtbaar bleven in het pro- 5  
ces. De conclusie was daarom dat guided-co-constructie met expliciete aandacht 6  
voor modellen kan leiden tot verwerven van kennis begrip van modelleren. 7

## Tweede experiment 8

In de derde studie is het experiment van interventie I verder aangepast en inge- 11  
voerd op vier scholen. Belangrijkste aanpassing was het toevoegen van ‘prototy- 12  
pelessen’. In die lessen werd leerlingen de gelegenheid geboden om te reflecteren 13  
op het proces van ontwerpen en bouwen. 14

De analyses van dit tweede experiment zijn verdeeld over twee studies. Uit de 15  
eerste studie, vooral op basis van kwantitatieve data bleek dat twee scholen, uit 16  
elke conditie één, veel beter op de kennistests scoorden. Verdere analyse wees uit 17  
dat deze scholen expliciet het functioneren van modellen ook verbinden met de 18  
theorievakken. Daarnaast hadden de scholen een kleinere leerling/leraar ratio. 19  
In de tweede studie bleek uit kwalitatieve analyses dat op de twee goed scorende 20  
scholen er meer modellen van de producten langer zichtbaar bleven in het proces, 21  
verder uitgewerkt waren en dat ze nadrukkelijk functioneerden als tools in dat 22  
proces. De conclusie was dat op die scholen het ontwerp en constructieproces 23  
het meest leek op dat van professionele productontwikkelaars. Als gevolg daarvan 24  
werden de leerlingen mogelijk beter geoefend in het benaderen van problemen 25  
op een beroepsmatige én academische manier: hun ‘disciplined perception’ werd 26  
beter ontwikkeld. 27

## Conclusie & discussie 28

De hoofdvraag van het gehele onderzoeksproject was: zijn de leeruitkomsten van 31  
leerlingen, die deelnemen als ontwerpers in een proces van guided co-constructi- 32  
on met peers en experts (leraren), beter dan de leeruitkomsten van leerlingen die 33  
leren te werken met kant en klare modellen, aangereikt door de leraar? Het ant- 34  
woord daarop is tweeledig. Er kan geconcludeerd worden dat de studenten leren 35  
modelleren en dat guided-co-construction nagenoeg dezelfde resultaten oplevert 36  
als een ‘providing’ aanpak. De opdracht van de tandemdriewieler was kennisrijk 37  
en de natests van de experimenten bewezen dat er na de interventies geleerd was 38  
op het gebied van wiskunde en modellen. Toch denken we dat de strategie van 39

1 'guided co-construction' leerlingen helpt bij het leren van gecodificeerde kennis  
2 en begrip van modelleren. Ten eerste omdat de modellen van de leerlingen in de  
3 experimentele conditie van het eerste experiment beter waren. Daar werden de  
4 modellen als tools voor communicatie en oriëntatie gebruikt. Ten tweede omdat  
5 in het tweede experiment op die scholen die iets beter presteerden, er meer en  
6 verder uitgewerkte modellen langer deel van het proces bleven uitmaken. Daar  
7 was het voor de leerlingen mogelijk in de praktijklokalen tegelijk kennis en vaar-  
8 digheden op te doen die zowel betrekking hadden op de beroepspraktijk als op  
9 academische vakken als wis- en natuurkunde.

10 Het vmbo is complex. Niet alleen vanwege het duale van de praktische en alg-  
11 meenvormende doelen, maar ook vanwege de dynamiek op de scholen. De bena-  
12 dering van de formatieve interventie helpt die dynamiek begrijpen. Met behulp  
13 van de videodata hebben we tijdens, maar ook achteraf, zicht kunnen krijgen op  
14 ons onderzoeksproces. In de video is met terugwerkende kracht te zien dat er  
15 sprake was van wederzijdse erkenning tussen onderzoekers en leraren. Video, in  
16 design based onderzoek in het bijzonder, bewijst daarmee dat het een onmisbaar  
17 instrument is in onderwijsonderzoek dat zich ook direct richt op ontwikkeling  
18 van de praktijk. Gevolg is dat door video-analyse ook duidelijk werd dat er meer  
19 kwalitatieve micro-analyses nodig zijn om te weten te komen wat er tijdens het  
20 werken aan authentieke opdrachten precies geleerd wordt. Tegelijk heeft het ge-  
21 bruik van video tegelijk ook de methode en het theoretisch kader helpen ontwik-  
22 kelen.

23 Na een decennium van onderzoek op het gebied van providing versus co-con-  
24 structie zijn we met hulp van gedetailleerde video-analyse op een punt aangeko-  
25 men dat gedefinieerd kan worden als de studie naar het aanreiken van modellen  
26 *binnen* een context van guided-co-construction en manieren van het zinvol ge-  
27 bruiken van tools en gecodificeerde kennis tijdens het proces van ontwerpen en  
28 bouwen van producten door leerlingen.

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

33

34

35

36

37

38

39





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# Curriculum vitae

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Martijn van Schaik (1974) is educational researcher & teacher, studied at the Fontys Sporthogeschool (previously ALO), worked as a teacher physical education, graduated at the vU University Amsterdam in theory & research in education and received his Phd there. Currently he is a teacher trainer and researcher at Hogeschool Amsterdam (university of applied sciences) and working on a documentary.

