Modelling across the Disciplines in Simulated Workplaces in Schools.

A Report of a Design-Based Research Project.

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Abstract

This article is a report of a design-based research project that consisted of three phases: a case study (n=20), a first experiment (n=65) and a second experiment (n-84). In every phase students worked on an integrated assignment: design and built a tandem tricycle. Main question of the overall project was: are the learning results of students participating in a process of guided-co-construction with peers and experts better than the results of students that have ready-made models provided by the teachers? The tricycle assignment proved to be knowledge-rich and the results of the posttests showed positive effects of student learning on mathematics and science. There are clues to suppose that the strategy of 'guided-co-construction' can support students to acquire codified knowledge and understanding of modelling.

Keywords: modelling, vocation education, disciplined perception

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This paper reports on a design based research project conducted between 2006 and 2009 in pre-vocational secondary education(VMBO[2]) in which students follow a general curriculum with a vocational perspective.

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

In the first section below the theoretical framework and a methodological overview of the project is given. In the next sections those questions are addressed by providing a chronological summary of the findings of each study. We will end with some remarks on educational theory and practice and propose some suggestions for further research.

Theoretical framework

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, 2004; Griffiths & Guile, 2003; 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” and “informal” returned 44 journal articles of which 14 concerned vocational education. None of them were empirical studies investigating the learning environment. Another search on pre-vocational

2VMBO is preparatory senior secondary education. It is 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).

education journal articles at the secondary level returned 15 hits, three of which concerned the learning environment.

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

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

Models as tools

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

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

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

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

Guided co-construction

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

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

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

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

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

Research questions

The theoretical background sketched above leads to the following overall research question: do students, who participate as model designers in a process of guided co-construction with an expert (teacher) and peers, show better learning outcomes than students who learn to work with ready-made models provided by the teacher?

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

Design

The project is a design based research project with three phases or iterations (The design based research collective, 2003). Based on findings from a case study (Study 1) and a first intervention (Study 2), we re-designed an educational programme for students in vocational education aimed at modelling for a second intervention (Study 3 and 4) (Van Schaik, Terwel & Van Oers, in preparation a, in preparation b). All together six schools, about 150 students and 27 teachers participated in the project.

As a design research project, we wanted to study the interventions in authentic contexts. An appropriate way to characterise our interventions would be to place it in the tradition of formative intervention (Engeström, 2007, 2009).

In all phases of the project video was used for observations and interviews. With a three-camera approach teaching practices were recorded, two cameras capturing an overview of the classroom and a third camera was handheld. The handheld camera was operated by one of the researchers and recorded interactions between teachers and students following a protocol (more information in Van Schaik, 2009, 2010). Analyses were conducted over the merged recordings of the three cameras. The video data played a crucial role in the research. First, the video data helped determining the redesign of the interventions. Second, also the method of design based research could be reviewed and adjusted to the typicalities of VMBO. Finally, in hindsight the development of the theory became visible: the perspective changed in the course of the project on the basis of the subsequent findings in the interventions.

In Study 1 we used a qualitative approach and conducted a pattern analyses on video data. In the subsequent interventions both pre- and post-tests as video observations were used in an experiment (trial) with a control group.

A narrative of the design-based research

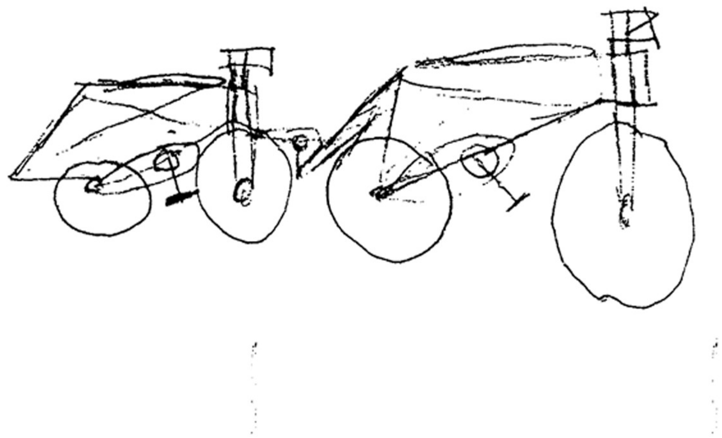
Case study (Study 1)

In a case study (Van Schaik, van Oers & Terwel, 2011) we explored the implementation of two assignments and the subsequent teacher guidance at one school and tested whether or not the learning environments became knowledge-rich (Guile & Young, 2003) as a result. Knowledge-rich workplaces are assumed to engage students in meaningful activities and at the same time promote subject matter learning (including mathematics, see Kent, Noss, Guile, Hoyles & Bakker, 2007). In other words, the learning environment has the potential for students to acquire knowledge that is codified or disciplinary.

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. Students first received an assignment to design (on paper) a tandem 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. The total duration of the project for the school was 12 weeks.

Most of the data we gathered came from observing two practice lessons a week during seven weeks with the three video cameras (thus a total of 14 lessons of 45 minutes).The video data was subjected to multiple viewings to explore the footage for patterns. We used this method, known as pattern analysis (Erickson, 2006; Terwel, 2005), to allow the observers watching the videos to detect patterns in the data. These patterns are called *a posteriori* patterns. A pattern is a formal description of a repeating structure in interviews and in interactions. Patterns can be mentioned by the participants in interviews or can be noticed by the researcher during observation. Analysis was performed on the video data and the materials that the students created in their projects (such as drafts, designs, drawings and calculations. See figure 1.) exploring only the a posteriori patterns. This resulted in three patterns.

***Figure 1.* Design drawing of a tandem tricycle drawn by students**



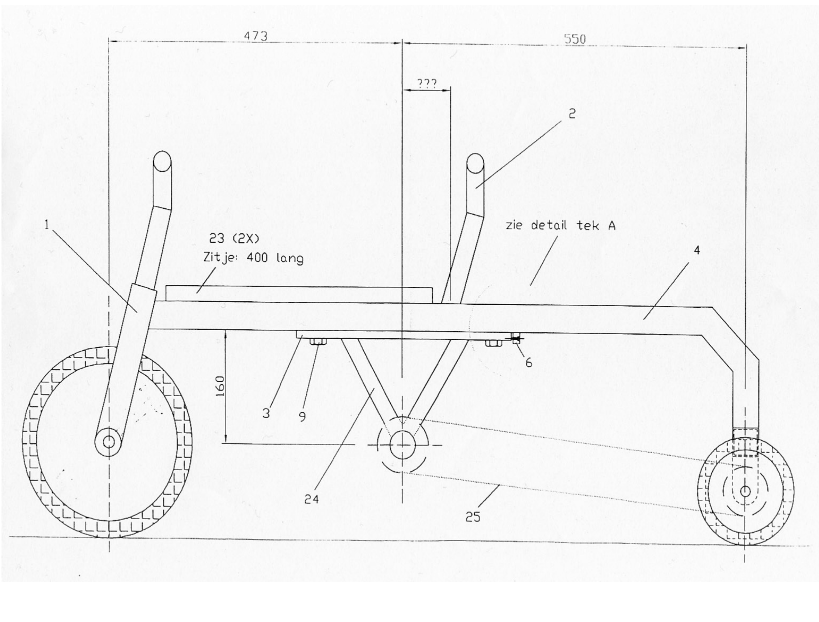
1. "Let your mind work" outside the workplace, because time is scarce.

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

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

As we focus on the students' problem solving, it appears that two different activities occur. First, students design situational models themselves when they are drawing the design or are planning their client interview. Second, canonical models, like models for technical drawing or mathematical rules, are provided by the teacher (see figure 2). As a result, no reinvention of these models occurs. The guidance teachers give on the canonical tools is one of providing students with answers or instructing students how the models should be used, whereas the guidance on the drafts and drawings of the students themselves helps students to transform drawings into the construction of a working model.

Figure 2: Construction drawing by the teacher



3. A workplace simulation is stimulating

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

These results showed that designing a tandem tricycle did, in fact, create opportunities for teaching students' codified knowledge and modelling. The teachers, however, tended to simply provide ready-made models while for the students the knowledge involved remained situated. That is, as solutions to problems, mathematical and scientific concepts and models tended to be bound to the (practical) situation in which they were constructed. Although the assignment itself was potentially knowledge-rich from the teachers' perspective, students could not relate the provided problem solving models to more general codified knowledge. Our assumption is that if the models had been designed by the students under teacher guidance, the role of models as tools would have become clear and the relation between theory and practice might have become more transparent in the process.

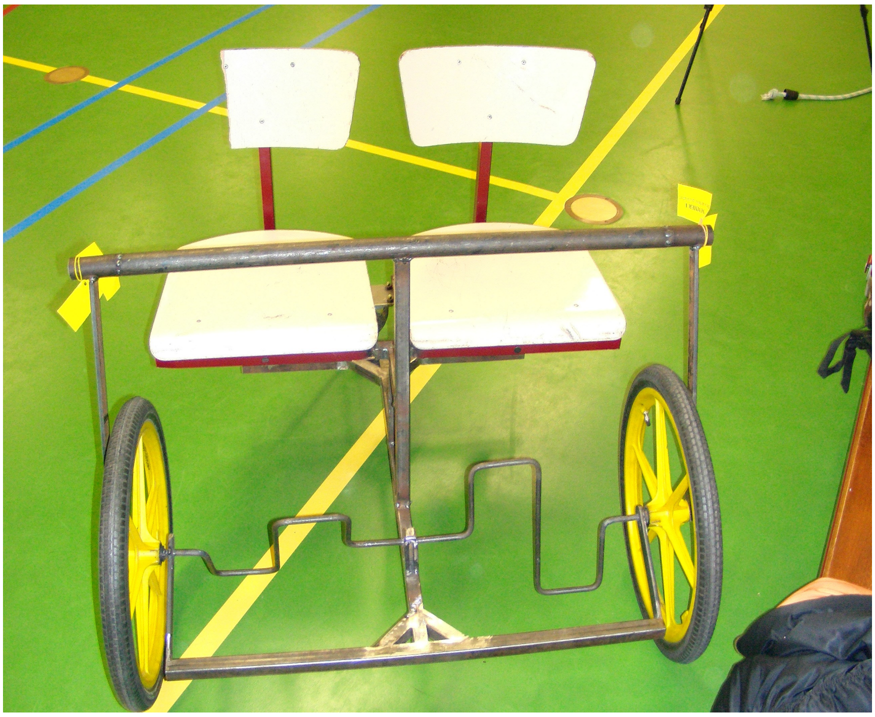
We also learned from the case study that student design processes should not be disconnected from actual construction; not only for motivational reasons (students who did not construct their designs were disappointed), but also because the transitions from design to construction turned out to be the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

First experiment (Study 2)

Next, for Study 2, two conditions were shaped in a pre-and post-test control group design: a 'providing' condition (control group) and a 'guided co-constructing' condition (experimental). This first experiment was an intervention at two schools following the case study. A programme based on the tricycle assignment was designed and teachers were trained to guide the students either in a co-constructive or in a providing way (Van Schaik et al., 2010). 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.

Important change in the intervention for students was that they had to design a prototype of a tandem tricycle in a competition (see figure 3 for the winner). Instead of creating just a single product, now the students also had to think about the production process in the light of their final presentation for a jury. In turn this created opportunities to further discover general knowledge.

Figure 3: Winning prototype tandem tricycle



For the students the intervention took about 10 weeks. 65 students participated. Using existing knowledge tests pre- and post-knowledge was measured (see figure 4 for an example item). Pre- and post tests were almost identical. The tests also contained a modelling item asking the students to draw a motor in a cart (see figure 5).

Figure 4: Test item from pre- and post-test

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.

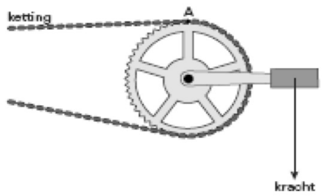
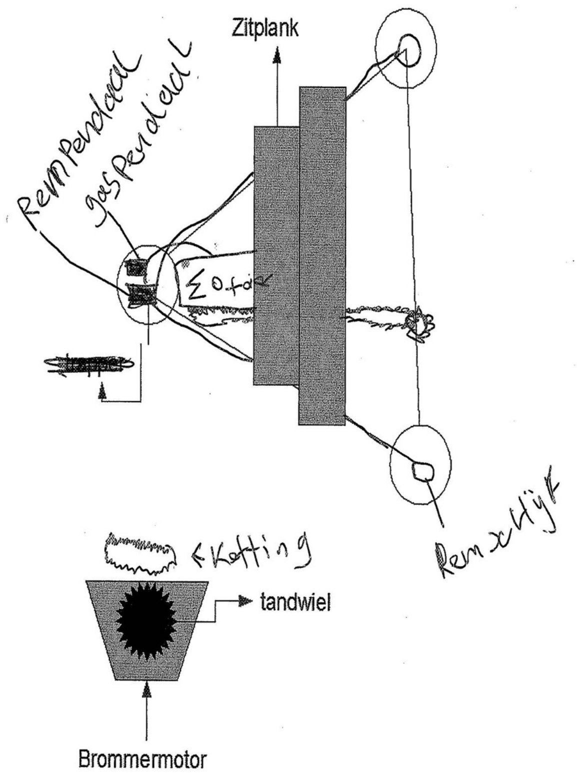


Figure 5: Modelling item from pre- and post-test



Next to the tests final drawings of every subgroup were assessed by design professionals according to criteria for design based on diSessa (2002). The interrater agreement was determined by Cohen's kappa (.86). Video observations and interviews as well as sketches, drawings and products of students and teachers were incorporated in the analyses.

It turned out that although the experimental group outperformed the control group on the knowledge-test (see Table 1), the two groups did not differ significantly when controlled for initial differences. With regard to modelling as measured in the tests, a trend was found that, adjusted for other co-variables, students in the experimental condition produced better models than students in the control condition.

Table 1: Scores on pre- and posttests.

	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

A regression analysis showed that a model that predicted the scores on the product-models by condition was significant (see Table 2). However, an interaction effect was found between age and condition. Younger students in the experimental condition scored better.

Table 2: Regression analysis for variables predicting the scores on the dependent variable modelling of the product.

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

1 Predictors: (constant), age in months

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

Group scores

These results of the 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. At the same time younger students scored better than older students. This could mean that younger students benefited more from the intervention due to the fact that the older students were the weaker students (they could be the ones that stayed back in class for example).

From the analyses of the qualitative data the models in the experimental condition indeed functioned as tools in the design and construction process. However, the models in the control condition remained visible longer during the process. Therefore the conclusion was that guided co-construction with explicit attention for modelling could lead to acquisition of knowledge and understanding of modelling.

Final experiment (Study 3 and 4)

Phase 3 consisted of two studies (3 and 4) in which the intervention was further developed and implemented at four schools. Main adjustment of the intervention was the incorporation of 'prototype lessons' to maintain explicit attention for modelling. In those lessons students were guided in reflection on the process of designing and construction. Pre- and posttests measuring knowledge and modelling were conducted as in the previous experiment. In addition vocabulary and the g-factor of intelligence were measured (J. Raven, J. C. Raven & Court, 2000). Again video observations and interviews were conducted. In total 87 students divided over 4 schools participated in this final experiment. The analyses are divided over two studies.

Quantitative study 3

The study based on quantitative data, showed that two schools, one from each condition, scored better on the posttests (see Table 3). Consequently, explanation of the differences on the knowledge tests – after controlling for initial differences – had to be found at school level. Keeping constant the other variables, both School 2 and 4 scored higher on the knowledge test (Table 4). However this was not significant.

Table 3: Descriptives of pre- and post- measures

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

* Maximum score on pre- and posttest is 47

Table 4: Initial average scores and adjusted means on post-test scores at school level

	Vocabulary	SPM	Pre-test	Adjusted post-test
Experimental group				
School 1	69.03	38.83	13.81	18.50
School 2	75.00	47.50	26.93	21.15
Control group				

School 3	64.81	42.32	14.07	19.30
School 4	57.82	44.73	23.33	22.96

Our hypothesis that students in the experimental condition would outperform their counterparts in the control conditions, had to be rejected. It needs to be noted that students at School 2 scored high on all pre-measures, whereas students at School 4 scored low on vocabulary. In average students scored 50 per cent on the knowledge tests.

A first analyses of qualitative data showed that these schools explicitly connected modelling to the general subject matter, such as mathematics and physics. Moreover these schools had a smaller student/teacher ratio. Better performing school had less students per teacher (see Table 5).

Table 5: Student/teacher ratio

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

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

Qualitative study 4

For the second part of the final experiment, Study 4, we continued our analyses by an in-depth qualitative study to find the determinants that might explain differences in learning outcome at school level. First of all, in Study 4, the goal was to examine precisely how the design was enacted at each school. Next, we aimed to establish how the activity of modelling developed with the process of constructing a tandem tricycle. Moreover, we sought to find out if modelling actually brought together practical experiences and the codified theories of the general curriculum. The main focus of this analysis was to find the key determinants of a microlevel pedagogy that supports students' use of representations as tools. We mainly used the observational and interview data. All products, drawings and other artefacts were considered in the context in which they appeared. The representations that appeared in the observations were classified according to three categories, initial sketches, elaborated and refining drawings, and final and presentation drawings. According to MacDonalds and Gustafson (2004) these are the types of drawings professionals use in their design process. Table 6 shows the categories and the clues by which they were established. We used the clues and categories for the representations we found in the observations.

Table 6: Categories and clues for drawings (from MacDonalds & Gustafson, 2004)

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

Based on the analyses of the interactions with models, a vignette was made for every school, especially focussing on the process of modelling.

School 1
Drawings and models are little in-between-assignments with hardly any reference to the actual construction. Teachers in the practice workspace helped the students with practical problems, without explicitly referring to mathematics, science or other codified knowledge. General subject matter is disconnect from the vocational practice.

School 2
The drawings and representations created by the students develop continuously from initial sketches to final drawings, and are used by the students themselves as well as by the teachers as a tool on which to reflect. General knowledge is implicitly referred to.

School 3
Drawings and models are almost non existent in the workshop, only internet pictures or the initial computer drawing were used as reference. Hardly any relations to curriculum subjects were mentioned. The prototype lesson was an introduction to the practical problems of tricycle construction.

School 4
Drawings and models remain visible during the whole process. By drawing and questioning, the teacher relates the practical issue of construction to the theoretical concepts of

transmission, speed and ratio, as well as to other practical examples. General subject matter is disconnect from the vocational practice.

The conclusion was that the use of models at two schools resembled the practice of professional designers more than at the other schools (MacDonald & Gustafson, 2004). Teachers and students used their models as tools for orientation and communication, which engaged the students more authentically in the reality of the workplace. As a result, the students were presumably better supported at these schools in approaching problems in a vocational as well as an academic fashion (Van Schaik et al., in preparation).

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

In addition to addressing the overall research question the four studies also resulted in a closer analysis of the research process and, in particular, the use of video in design-based research. 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 et al., in press; Van de Pol, Volman & Beishuizen, 2011) this study is the only one that combines the perspective of the students and the role of the teachers by using an intervention that incorporates process data (e.g. video) and output measures (knowledge tests). It resulted in findings that are in line with the other studies. With Boersma et al. (2009) we agree that students are motivated by 'real' assignments. That is, tasks which, as Koopman et al. (in press) argued, should be oriented towards delivering a 'product'. The fact that we observed only two schools at which teachers were able to link students' practical problems to theory, concurs with the results in Van de Pol et al. 2011), in which observed teachers showed few examples of guidance that were contingent on student capabilities.

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

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

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

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

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

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

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

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

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