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

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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 10-week period. The experimental sample comprised two 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.

Keywords: vocational education; modelling; providing versus guided co-construction

Introduction

To strengthen the relation between theory and practice, schools for preparatory vocational secondary education (VMBO)¹ in the Netherlands and elsewhere are reforming their curricula (Biermans et al. 2004; Guile and Young 2003; Mittendorff et al. 2008; Boersma et al. 2009). The reform is aimed at engaging the students in work-related school assignments. The general question arises whether such assignments in fact improve the relation between theory and practice, and what knowledge could be acquired by working on such authentic assignments; in other words, whether understanding is fostered and if so, to what extent. This general question prompts two processing questions: if improvement is found to be significant, how do concepts and models become tools in gaining understanding of the knowledge domain they relate to?, and how do they aid the search for solutions to practical problems?

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

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

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

In the present study we build on these previous findings and report on an intervention. The focus is on codified knowledge and the understanding that students acquire when working on design and construction projects. We expect that by designing a technical product with teacher help, students will be stimulated to improve, first, their understanding of technical and scientific concepts and principles and, second, the

rules and their interrelations as represented in models (see for example, Kolodner et al. 2003). The models thus become tools in practical problem-solving while, at the same time, providing a basis for connecting practical use to theoretical knowledge. In contrast to our first case study, teacher guidance is more collaborative. The main issue in this research is whether co-constructing teacher guidance has a positive effect on codified knowledge and modelling.

Theoretical background

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

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

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

Although there are many different definitions of models, in this article we follow van Oers (1988), who states that '...a model can be described as any material, materialised (for example, a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's actions ...' (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 drawing, plans and ideas are used to plan and predict the process, and to discuss the final design. The models give 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, cited 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 and 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 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 workplace practice, as well as to recognise the students' emergent need for mathematical tools, and to relate such recognition to the practice of (mathematical) modelling (van Oers 2001). However, providing models is not sufficient to understand the use of models as tools; in addition, conditions should be created which focus '...on the hidden rules and assumptions in the tools' (van Oers 2001, 81). Teacher guidance should therefore promote such understanding by helping students to co-construct the models.

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

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

In a community of practice,

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

Method

Research context and participants

This study may be regarded as a design experiment (Barab and Squire 2004; Collins, Joseph, and Bielaczyc 2004; The Design Based Research Collective 2003; Shavelson et al. 2003). Based on case study findings (van Schaik, van Oers, and Terwel 2010), we designed an educational programme for students in preparatory vocational education aimed at modelling. A pre-test-post-test control group design was used. The effects of the intervention were determined after controlling for initial differences, e.g. student characteristics and pre-knowledge. Due to the naturalistic nature of the design experiment, not all possible variables were controlled for. For example, content of subject matter classes, group composition, teacher experience and actual time spent on the assignment, as well as students' previous experience with these kinds of assignments could all affect the outcome. Consequently, in addition to test scores, interviews and video observations were used to study the intervention process.

As a characteristic design-based research, this study is also intended to further develop the concept of intervention. As such it may be regarded as a pilot study situated between the first case study and a larger experiment.

The participants in this study were a group of 15-year-old students ($n = 65$) at two schools for preparatory vocational education. During the practice lessons, students in both conditions worked in mixed groups of the two lowest learning tracks: basic and staff level.² We assigned both schools to the condition that best fitted their everyday practice, as explained above. This means that we adjusted the training and guidelines of the programme in this intervention to the teaching practice of the schools, which we identified during a visit and from interviews with the teachers. The school in the experimental condition works with authentic assignments over the complete curriculum from first to fourth grade, including mathematics and science. Students at that school are used to initially solving problems themselves and are stimulated to come up with their own models and solutions. Teachers guide them in the exploration process. Students finish their projects with an individual portfolio assessment by the teacher. The teacher's teaching methods in the experimental condition most resembled our assumptions on how to guide students to understand and use models in a co-constructive way.

The school in the control condition works with authentic assignments as well, but only in the practice lessons. Theoretical subjects (mathematics, science) are taught in the more traditional way of direct instruction. In addition, the practice teachers tend to *provide* the solutions to practical and theoretical problems. This means that when a problem is identified, after identification by the teacher, a solution is instantly provided. For example, when a student wishes to know how to determine the length of a piece of steel from a drawing, the teachers simply provides the formula. At the

end of every assignment students are graded for their product and presentation. All the student has to do is work out the solution. In other words, the school's approach is consistent with the more traditional way of providing models.

Intervention

The intervention started with a session with the teachers in which the aim of the intervention was explained and discussed. The teachers were provided with an educational instrument that consisted of a lesson plan and examples of problems that might occur during the students' design processes. Teachers were supposed to pay explicit attention to relating situated knowledge to more general knowledge; moving from practical problems to modelling by the use of mathematical and scientific concepts.

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

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

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

Assignment

Students were asked to design and construct a prototype of a tandem tricycle. Teachers assisted the students in solving problems of design or production that might occur. The students were stimulated to use or develop models to solve the problems they were faced with while working on this 'real-life' assignment. The student assignment was

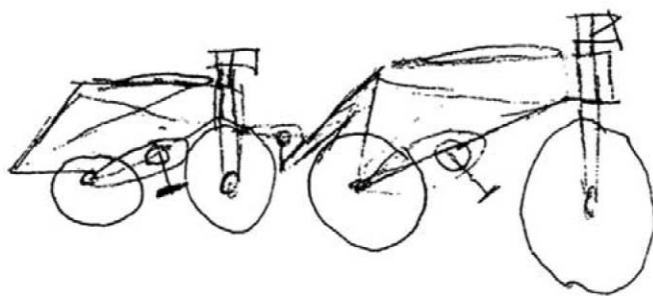


Figure 1. First design drawing by a group in the control condition.

formulated as follows: ‘*Design and build a prototype of a tandem tricycle for children aged 4–7 in such a way that the children have to cooperate in the process of cycling*’.

The assignment was placed in the context of a competition. The tandem tricycle had to be designed and constructed in a 10-week period by the students. During that period they worked at least two hours a day in the workshop setting and in open classrooms where computers were available. In both spaces teachers were available for questions and guidance. The design process was reflected on and discussed during workshop hours and in lessons or sessions separate from the workshop and the construction process. During workshop practice mainly practical problems occurred. These were mostly solved on the spot or redirected to the separate lessons. During the separate lessons the students were guided by teachers in problem-solving with the aid of models, while using their designs and applying their knowledge of science and mathematics. The students’ involvement started with an introduction by the researchers, in which the aim of the assignment was explained: building a prototype to win a competition. The students subsequently started designing during the first week (see Figure 1 for an example), moving on to construction during the weeks following. The competition ended with the selection of the two best prototypes for each school, followed by a finale during which a panel of judges decided on the winning prototype design (Figure 2).

Instruments and procedure

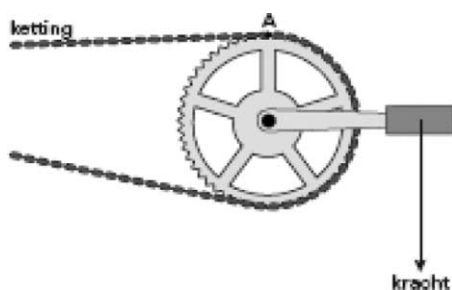
To measure the students’ pre-knowledge of mathematics and vocabulary, we administered several tests. The first were two pre-tests, one measuring vocational knowledge, the other measuring understanding of modelling. The knowledge test consisted of 17 items, derived from national exams, to test mathematical, scientific and technical knowledge. The maximum score was 37 points, with Cronbach’s alpha as .78. Figure 3 represents a sample item from the knowledge test.

The modelling test consisted of a semi-structured item on how to construct a cart engine plus a visualisation and drawing task (see Figure 4). The post-knowledge and post-modelling tests were almost identical to the pre-tests (Cronbach’s alpha for the post-knowledge test was .82).

The second test of understanding besides the modelling pre- and post-tests involved an assessment of the students’ final drawings of the products that had been designed and constructed by them (see Figure 5). A team of four experts rated the drawing by each group according to four criteria on a 4-point Likert scale. The criteria were derived from diSessa (2002), as applied by van Dijk (2002), representing criteria for a qualitatively effective model: structure, clarity, accuracy and completeness. The



Figure 2. The winning tricycle of the competition, chosen by the panel of experts.



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

- A: the force in A is smaller than that on the pedal.
- B: the force in A is the same as that on the pedal.
- C: the force in A is greater than that on the pedal.

Figure 3. Sample item of the knowledge test.

experts, who were developers of 3-D modelling software, scored the models without knowing the conditions under which they were constructed. Inter-rater agreements were determined by Cohen's kappa (.89). The final tricycles were also rated by the same experts. However, since the inter-rater agreements proved unsatisfactory, we did not use them for our analyses.

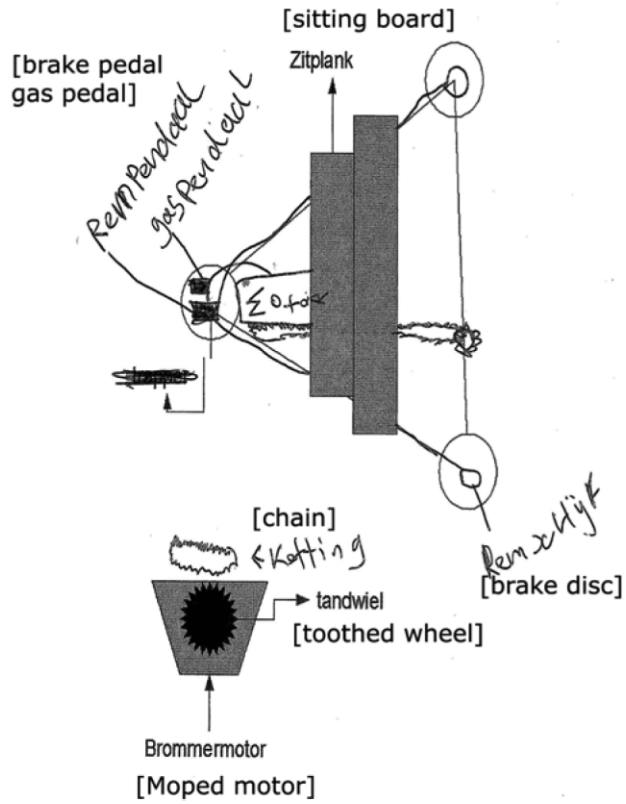


Figure 4. Modelling test item.

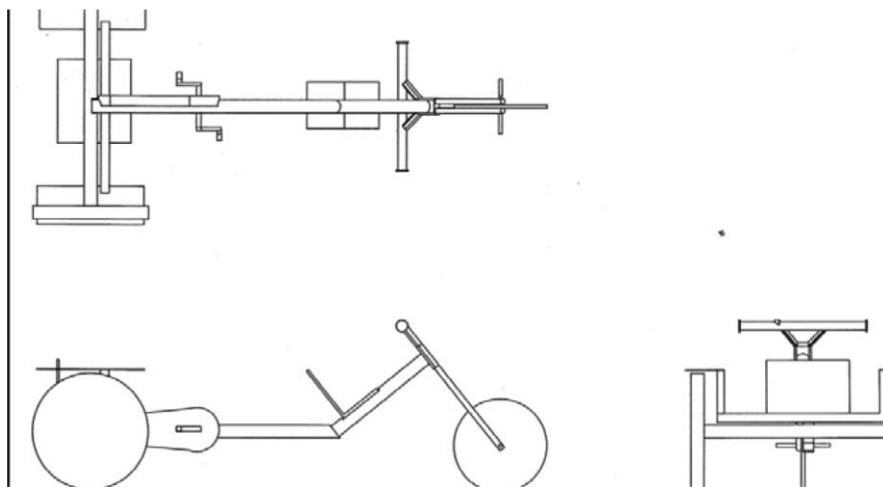


Figure 5. Final product drawing by a group in the experimental condition.

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

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

Results

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

Table 2 presents the correlations between the main variables. The relation between the variables is further explored by means of regression analyses.

The regression analyses are divided into three categories of outcomes, according to the three separate research questions (and their three dependent variables). We will first consider the learning outcome on knowledge; we will then address modelling as measured by means of the tests; finally, we will examine the final product models of the students as rated by modelling experts. As shown in Table 2, we started with the

Table 1. Descriptive statistics and pre- and post-measures.

	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 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**

Notes: *Correlation is significant at 0.05 level (two-tailed); **correlation is significant at 0.01 level (two-tailed).

main variables for each regression analysis. Only the statistically significant results are reported.

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

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

Modelling as measured by the post-test in modelling

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

Modelling of the product

The final outcome variable, i.e. modelling of the product, consists of the final product model, as drawn by the students and rated by modelling experts. It should be noted that these drawings were group products, and that the group scores were assigned to

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

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

Notes: ¹Predictors: (constant), age in months; ²Predictors: (constant), age in months, interaction age × condition.

Table 4. Coefficients of regression of the predictors on the dependent variable modelling of the product (unstandardised scores).

Model 2	Unstandardised coefficient		Standardised coefficient		
	<i>b</i>	Std. error	<i>b</i>	<i>t</i>	Sign.
(Constant)	110.04	58.69		1.88	.070
Age in months	-.49	.30	-.32	-1.65	.109
Interaction age \times condition	-15.15	5.64	-.51	-2.69	.011

individuals in their groups. Tables 3 and 4 present the outcomes of the regression analyses.

Model 2 in Table 3 shows that 63% of the variance can be explained by the predictors age and the interaction variable age \times condition. The variables pre- and post-knowledge, pre-modelling and vocabulary were not significant. Younger students scored better on drawing the final model.

Looking at the coefficients, the interaction variable predicts the score negatively (Table 4). This means that younger students benefit more from the experimental condition than older students. Although our final hypothesis, namely that students in the experimental condition produce better drawings, could not be confirmed; there was an interaction effect of age \times condition. It turned out that younger students in the experimental condition performed better on their final drawings than their counterparts in the control group.

Enactment of the programme

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

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

The main differences in enactment were time spent on the assignment and the way students finished the assignment, as concluded on the basis of the diary we kept as well as the actual school schedules. Regarding the time spent on the project, the experimental condition took fewer weeks than the control condition (three weeks in all). The project for students in the experimental condition appeared more condensed. The project in the experimental condition was fitted more strictly into the school semester. Although

the project at the school in the control condition took more time, this was not the case for all students. After finishing the first semester students were regrouped and the two as yet unfinished tricycles were worked on by partly new groups. Moreover, according to the content-logged analyses for the practice classes, only a few students in the experimental condition worked on the tricycle during the practice lessons. Others continued working on other assignments. Apparently, the curriculum was more adaptive: students maintained their own speed and pace in their activities, whereas the other students in the control condition were to a much greater extent at the same point in their programmes and projects.³ In addition, the students in the experimental condition finished the semester for which their assignment was planned with an assessment, whereas their counterparts ended theirs with a presentation for peers and teachers.

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

Excerpt 1: experimental condition

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

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

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

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

By contrast, in the control condition explicit attention was maintained on the models during the entire project. However, attention was focused on representing the models correctly in construction plans rather than on using models as tools. In the transcript below (Excerpt 2) a discussion between the teacher and students in the control condition shows how the teacher asks the students about their ideas and shows them how to draw their designs.

Excerpt 2: control condition

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

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

The discussion continues and turns to transmission.

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

Conclusions and discussion

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

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

In a community of practice,

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

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

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

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

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

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

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

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

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

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

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

All in all, the students in the experimental condition gained in mathematical and scientific knowledge to the same extent as those in the control condition. We may therefore conclude that 'haphazard' acquisition of such knowledge in the practical

context of designing and constructing is able to compete with explicit, traditional instruction in mathematics and science. This conclusion may be seen as an advantage, especially for practically oriented students in vocational education. Finally, with regard to modelling, a trend was found to the effect that students in the experimental condition outperformed their counterparts in the control condition. This suggests that co-constructive teacher guidance may facilitate students' understanding of models as tools for communication and orientation.

Notes

1. VMBO is the Dutch name for secondary education for students 12–16 in their preparation for senior secondary vocational education. Sixty per cent of all Dutch students aged 12–16 attend VMBO (Maes 2004). In this article we will use 'vocational education' to refer to VMBO.
2. In VMBO students are divided into four 'learning tracks'. They differ on the theoretical level of the subject matter. The four levels are labelled 'basic level' (lowest theoretical level), 'staff level' (second theoretical level), 'mixed level' (intermediate level) and 'theoretical level' (highest theoretical level).
3. 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.

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