Learning in the workplace at school: knowledge acquisition and modeling in preparatory vocational secondary education.

Martijn van Schaik[a*] , Bert van Oers[a] and Jan Terwel[a]

[a] *Department of theory and research in education, VU university, Amsterdam, The Netherlands*

*Corresponding author. Email: m.van.schaik@psy.vu.nl

ABSTRACT

In vocational education, is it better to guide students in designing their own models as compared to providing students with ready made models? In the workplace at school, students work on real-life assignments and teachers guide them in building the product and learning the necessary concepts and skills. In the process of designing the product, models need to be used. In a ten week period students had to design and build a tandem tricycle. The sample comprises 2 schools and 65 students, age 15 years. A pretest-posttest control group design was used. The two conditions differed in the way models were taught: in the experimental condition the models were co-operatively designed by the students under guidance of the teacher; in the control condition ready-made models were provided. It was hypothesized that the students in the experimental condition would outperform their counterparts in the control condition on knowledge and modeling. However, both groups scored equally well on the post knowledge test in science and mathematics. The experimental group gained more on modeling. Implications for teacher guidance and school climate are discussed.

Keywords: vocational education, modeling, providing versus guided co-construction.

INTRODUCTION

Learning in simulated workplaces in vocational education is assumed to motivate students and teach the students the concepts, skills and attitudes necessary for further education and later employment (Anoesjka Boersma, Ten dam, Volman, & Wardekker; Mittendorff, Jochems, Meijers, & Brok, 2008; Van der Sanden & Teurlings, 2003). In preparatory vocational secondary education (VMBO[1]) students are working in those environments on authentic assignments such as a wine rack, a trike or are repairing the cars of their teachers in a 'community of practice' (Lave & Wenger, 2005; Van der Sanden, Terwel, & Vosniadou, 2000). In a previous case study was found that working on those assignments creates opportunities for acquiring understanding (Van Schaik, Terwel, & van Oers, 2009). However, due to the character of the learning environment, that is focussed on producing a product, simply getting the assignment done will not lead to knowledge acquisition and deeper understanding of modeling and related knowledge. Deeper understanding may emerge in a 'knowledge rich' learning environment. It is the kind of guidance by the teacher that is crucial. The aim of this article is to determine whether guiding students in a co-constructive way leads to better results than providing the students simply with the knowledge and tools they need.

In our research we are interested in the construction of models and knowledge in a knowledge rich learning environment. Research has shown that the strategy of guided co-construction may lead to a better understanding of mathematics and modeling (Doorman, 2005; Terwel, Van Oers, Van Dijk, & Van den Eeden, 2009;Van Dijk, Van Oers, & Terwel, 2003). Whereas, just providing models often boils down to sheer transmission of the models. On the other hand, reinventing the models under guidance of teachers helps the students understand the function and   value of modeling (Gravemeijer, 1997). In addition, diSessa (2002; 2004) in his research found that students are very well capable of (re)inventing

1 VMBO is the Dutch name for secondary education for students 12-16 that prepares for senior secondary vocational education. 60 % of all Dutch students 12-16 attend VMBO (Maes, 2004)

graphing. Others have found promising forms of problem based learning and programs of problem solving in real-life contexts (Kolodner et al., 2003; Hill, 1998). However, it is not clear how this reconstruction of models works when students are working on real-life assignments.

At the same time (preparatory) vocational schools are reforming their curriculum and improving the relation between theory and practice by having the students work on work-related assignments (Biermans, Nieuwen, Poell, Mulder, & Wesselink, 2004; Guile & Young, 2003; Mittendorff e.a., 2008; Boersma, ten Dam, Volman, & Wardekker, 2009). A question arises what knowledge can be acquired by working on those authentic assignments and whether and how deeper understanding can be fostered. To put it differently, how concepts and models can become tools to understand the domain of knowledge, and solve problems.

By designing a technical product with help of the teacher(s) students can learn to understand technical and science principles, rules and their mutual relations as represented in models. The models become tools in practical problem solving and at the same time connect the practical use to theoretical knowledge.

In a previous case study we implemented an authentic assignment at one school for preparatory vocational education. In that study it was found that the guidance of the teacher tended to be a providing one. Although the assignment clearly included many opportunities to help students gaining a better understanding of mathematical and scientific models, the culture in the workshop setting at the school was one of 'getting it finished'. Hence, co-construction of models appeared to be situated and tacit. Which meant that the knowledge and models used were bound to the situation in which they came across and were not explicitly taught. The solutions for problems in those situations were provided by the teacher and no time was spent on further exploration on the mathematical and scientific concepts (Van Schaik et al., 2009).

In the present study we continue on this previous case study and report on a intervention in which we test, in a pre-test post-test control group design, the knowledge and understanding that students acquire when working on a designing and construction project. Main issue in this article is the question whether guiding students in a co-constructing way leads to better results on knowledge and modeling.

THEORETICAL BACKGROUND

The introduction of students into the sociocultural practices (workplace *and* mathematical) is best described as a process of legitimate peripheral participation (see Lave & Wenger, 1991). In this context learning can be seen as a process of qualitative change in activities that results in enhanced possibilities of participation in sociocultural practices (Van Oers & Wardekker, 2000). Likewise, learning as a microgenetic development can also contribute to *enculturation* into a community of learners (Brown & Campione, 1994; Lemke, 2000; Rogoff, Matusov, & White, 1996). As for learning in a workplace setting, such a community is best characterized as a *community of practice* (Lave & Wenger, 2005). In such communities of practice, learners are actively involved in meaning making activities and using tools and artifacts to solve problems and to communicate with each other and with others outside the community.

Furthermore, from socio-cultural theory it follows that in the accomplishment of activities new goals and needs may emerge, that drive us to construct or adopt new tools (See for example Kozulin, 2003; Saxe & Guberman, 1998). Hence, by participating, students may encounter new goals that encourage them to appropriate new practice-related tools like concepts, symbols and models (Gravemeijer, Lehrer, Van Oers, & Verschaffel, 2002). The teachers should be guiding this participation process and thus helping the students to 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 are taking part in the community and co-

construct the meaning with the students. In this guided co-construction process the teachers is not just a guide, but also a real participant (Van Oers, 2001).

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, materialized (for example a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's actions ...". Models function, in education as well as in science, as tools in a problem solving activity and are important in both individual and social cognitive processes (Van Oers, 1988). From a socio-cultural point of view, models have two core functions: orientation and communication, which are not mutual exclusive. Orientation, according to Gal'perin, is an essential moment of cultural actions. A model, in his point of view, is a cultivated tool for orientation on actions to be performed (Van Oers, 2006). It gives direction to a person's activities. As orientation is a cognitive activity, it includes valuation, producing information, planning, predicting etc.. As tools for communication, models foster the distribution of individual ideas and meaning across the community. When students work together on, in our case, for example the construction of a tricycle, the drawings, plans and ideas are used to plan the process, predict problems and to discuss the final design. The models give direction to the actual design and the planning of the activities, but also coordinate the ideas and actions among the participants. In other words, the models help to anticipate on the outcome (Gal'perin 1969;1979 in Van Oers, 2006), and to distribute meanings in a community.

In VMBO students are both designing and constructing real products. In the design process as well as in the actual construction, problems arise and need to be solved. To anticipate possible problems and their solutions, models can be used. For example, on the basis of a model angles can be calculated in a drawing in order to know how to saw the pieces of steel. Instead of trying to saw and finding out that the steel parts cannot be put together. Here the formula used to calculate the angel functions as a orientation tool.

Although drawings and models are important in design technology and serve both communication and generation of ideas, MacDonald & Gustafson (2004) claim that in classrooms the emphasis is on their representational function. If drawing by students in classrooms would be related to orientation and exploration of ideas, modeling may become an action and learning strategy for students by which they gain a deeper understanding of problems and their possible solution.

By reflection on the production process and improving it, members learn to understand the often tacit rules and codes of the workplace and the knowledge behind them. Models for a prototype could function as a tool to communicate and orientate on the anticipated production process and thus help students to think ahead and reflect on their own process. As a result, students' understanding could be fostered.

Guile and Young (2003) are critical on how participation by itself can foster learning. They argue that for knowledge acquisition in a 'community of practice' participation only is not enough. Teachers should be giving explicit attention to relating situated knowledge and more general knowledge. In the intervention in our study the program was aimed at just that: moving from practical problems to mathematical and scientific modeling and finally to understand the relevant domain specific concepts.

The important role of the teacher(s), guiding the students in knowledge acquisition and understanding from practice, also concerns introducing students into the mathematical practice of modeling. It is the teachers' role to identify the 'mathematical' in the practice of the workplace, to recognize the emergent need in students for mathematical tools, and relate that to the practice of (mathematical) modeling(Van Oers, 2001). Only providing the models is not enough to understand the use of models as tools, instead conditions should be shaped that focus " … on the hidden rules and assumptions in the tools." (Van Oers, 2001, p.81). Therefore, the guidance of the teacher should foster this understanding by helping the students co-construct the meaning of the models.

From the theoretical background above the general hypothesis is: *students who participate as model designers in a process of guided co-construction show better learning outcomes as compared to students who learn to work with ready-made models.*

Three research questions are formulated dividing the learning outcome in knowledge, modeling in a test and modeling in practice:

(1) Do students in experimental condition acquire more knowledge in the domains of mathematics and science?

(2) Do students in the experimental condition develop a better understanding of the use of models?

(3) Do students in experimental condition produce better models/drawings of their own product?

It can be expected that success in learning in the workplaces will, as in regular classrooms, depend on the student characteristics. Their ability, pre-knowledge and vocabulary influences the impact of the environment and the guidance of the teacher. For the required student performance in our study, vocabulary may be considered an important student characteristic. Vocabulary is generally seen as a reliable predictor of intelligence (Sternberg, 1987), as well as of knowledge level (Hirsch, 2006). Moreover, reasoning from a sociocultural point of view, language in general (and particularly words) is a powerful instrument for regulation of actions and orientation (Van Oers, 2006). On a theoretical basis we assume that these student characteristics may have an important role to play in students' construction and modeling. In our study they will be measured and treated as possibly relevant variables that may help explain the outcomes.

METHOD

Intervention

This study can be considered a design experiment (Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004; The design based research collective, 2003). Based on findings from a case study (Van Schaik et al., 2009) we (re)designed a educational program for students in preparatory vocational education aimed at modeling. In the present study a pretest-posttest control group design was used. The effects of the intervention were determined after controlling for initial differences e.g. student characteristic and pre-knowledge.

Students were to design and build a prototype of a tandem tricycle. Teachers assisted the students to overcome problems occurring during design and production of the tricycle. The students were stimulated to use or develop models to solve the problems they were faced with working on this 'real' assignment.

The intervention started with a session with the teachers where the aim of the program was explained and discussed. They were provided with an educational tool that consisted of a lesson program and examples of problems for students that might occur when designing. Teachers should give explicit attention to relating situated knowledge and more general knowledge. That is, moving from practical problems to mathematical and scientific modeling.

The differences between the conditions concerned the appropriation of modeling. In the control condition the models were ready-made and provided to the students as solutions to their problems, whereas in the experimental condition the students were stimulated to design or (re) discover the models themselves. We collaborated with the teachers at every school in order to adjust the educational tool to their needs and practices. At every school the daily routines and organization were different. Especially the way in which the theoretical subjects were integrated into the practical lessons and assignments was not the same at each school. Moreover, the practical workshop lessons in VMBO are subject to continuous change, often teams of teachers are responsible for the guidance in the workshop. Hence, to overcome the problem of limited usage of the educational tool by the teachers, the tool in both conditions was adjusted according to the practice of the school. Doing so, the agency of the participants and, as a result, the changing of the tools used by the participants when they start using it was taken into account. Therefore, the tradition of formative intervention (Engeström, 2008) is a better way of describing our method. And, at the same time, the complexity of studying the practice in the schools (Goodlad, Klein, & Tye, 1979) is acknowledged.

Participants

At two schools in preparatory vocational education 55 15- year-old-students participated in this study. During the practice lessons students in both conditions were working in mixed groups of the two lowest learning tracks: basic and staff level[1.] We assigned both schools to the condition that best fitted their everyday practice, as explained above. That means, in this intervention, that we adjusted the training and guidelines of the program 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 start solving problems themselves and are stimulated to come up with their own models and solutions. Teachers are guiding them in that exploration process. The pedagogy of the teachers resembled best our assumption on how to guide students to understand and use models in a co-constructive way.

1 In Dutch VMBO students are divided in four 'learning tracks'. They differ in theoretical level of the subject matter. The four levels are: 'basic level' (lowest theoretical level), 'Staff level' (second theoretical level), 'mixed level' (intermediate level) and 'theoretical level'(highest theoretical level).

The school in the control condition works with authentic assignments as well, however, only in the practice lessons. Theoretical subjects (mathematics, science) are taught in a more traditional way of direct instruction. Besides that, the practice teachers tend to *provide* the solutions to practical and theoretical problems. That means that a problem is identified by the teacher and immediately a solution is provided. For example, when a student comes up with a question on how to know the length of a piece of steel from a drawing, the teachers simply provides the formula. The student only has to work out the solution. In other words, the school's approach was consistent with the more traditional way of providing models.

program

The assignment for the students was:

Design and build a prototype of a tandem tricycle for children age 4-7.

The assignment was placed in the context of a competition.

In a ten week period students had to design and build the tandem tricycle. 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 during workshop hours and in lessons or sessions separate from the workshop and the construction process. During practice in the workshop mainly practical problems came across and were most of the time directly solved or redirected to the separate lessons. In the separate lessons teachers guided the students in problem solving with the help of models using their designs and relevant subject matter in science and mathematics knowledge came across. The process for the students started with an introduction by the researchers explaining the purpose of the assignment: building a prototype to win a competition. After that students started designing in the first week and moved on to construction in the weeks following. The competition ended with first the selection of the best two prototypes on every school and after that a finale with a jury deciding which prototype was the best.

--

Figure 1: first drawing of tricycle about here

--

--

Figure 2: picture of winner tricycle about here

--

The design of the program was primarily based on experiences in a earlier case study (Van Schaik et al., 2009) in which we explored workplace learning in vocational education and the knowledge richness of the assignment. We found that the assignment of designing and building a tandem tricycle can evoke the use of models and subject matter knowledge. However, to become a successful learning strategy, using models should be explicitly taught. Together with teachers and experts on modeling and mathematics the program was redesigned accordingly and adjusted to the two conditions. For the experimental condition the program was flexible and open in order to help the teachers guide the students in a more co-constructive way. For the control condition, on the other hand, the program was fixed in a sense that the content of the lessons was ready-made and direct instruction was used in those lessons.

Instruments and procedure

To measure the students' pre-knowledge, abilities and personal traits we administered several tests. Pre-test and post-test were divided in two parts: an knowledge part (test 1) and a modeling part (test 2). Test 1 consisted of 17 items, derived from national exams, testing mathematical, scientific and technical knowledge. Maximum score was 37 points and Cronbach's alpha was .78. In figure 3 an item example is depicted:

Figure 3: Power transmission about here

Test 2 was a semi-structured question on how to build a motor in a cart and the task to visualize that in a drawing (see figure 4). The post-knowledge and modeling test was almost identical. Another measure for understanding, apart from the modeling parts of the pre- and post-tests, was an evaluation of the final drawings of the product the students designed and constructed (see figure 4). A team of experts rated the drawing of each group on four criteria. These criteria were derived from diSessa (2002) as used by Van Dijk et al (2002) and represented criteria for a qualitative good model: structure, clarity, accuracy and completeness. The experts were developers of 3-D modeling software. The inter-rater agreement was determined by Cohen's kappa (.89). The final tricycles were rated as well, however, the inter-rater agreement was not satisfactory.

Figure 4: Drawing item in test 2 about here

Figure 5: Final drawing of the product of a group in experimental condition. about here

---

Guided co-construction requires a repertoire of concepts and words (vocabulary) to understand each other. However, students differ in their ability to verbalize, elaborate and explain their ideas and solutions. Consequently students may also differently benefit 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 is one of the predictors of the learning effects in this kind of learning environment. Therefore a vocabulary test was included as part of the measures to determine student characteristics at the start of the intervention. We administered a national vocabulary test with a reported alpha of .89 (N=2200). The vocabulary test was administered by means of computers.

RESULTS

From table 1 we learn that both conditions differ in age and pre- and post-test scores. However, further exploration on the differences by means of an ANOVA made clear that only differences in age were significant, $F(1,63)=49.29$, $p < .01$. In the control condition students are 10 months older (mean control group=199.6 months; mean experimental group= 186.2 months).

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

	M	SD	Min	Max
Control group (n=15)*				
Age (in months)	199.6	.55	15.83	17.50
Vocabulary	64.73	13.66	40	84
Pre-knowledge	15.25	8.95	2	30
Pre-modeling	2.61	2.48	1	8
Post knowledge	16.83	6.53	5	24
Post modeling	2.31	2.39	1	8
Experimental group (n=50)*				
Age (in months)	186.2	.55	14.67	17.17
Vocabulary	64.96	12.45	41	101
Pre-knowledge	13.02	5.44	4	29
Pre-modeling	3.69	3.49	1	12
Post knowledge	14.40	5.22	3	24
Post modeling	4.69	3.28	1	12

* Not all students accomplished all tests

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

Table 2. Correlations (N varies#, Pearson's correlation)

	Age	Vocabulary	Pre-knowledge	Pre-modeling	Post knowledge	Post-modeling	modeling product	Condition
Age (in months)		0.06	-.06	-.00	.05	-.19	-75**	-66**
Vocabulary			.15	.31*	.37*	.35*	.13	.01
Pre-knowledge				.23	.77**	.27	-.16	-.14
Pre-modeling					.20	.48**	-.15	.17
Post-knowledge						.23	.06	-.18
Post modeling							.09	.32*
modeling of the product#								.64**

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

* correlation is significant at 0.05 level (two-tailed)

not all students accomplished all tests and not all students finished their final drawing

The regression analyses are divided into three categories of outcomes according to the three separate research questions (and their 3 dependent variables). First we consider the learning outcome on knowledge, second we will address modeling as measured by means of the tests and finally we will come to the final product models of the students as rated by experts on modeling.

Knowledge

As far as Knowledge was concerned, the outcomes of the regression analyses did not confirm our hypothesis. After controlling for initial differences no significant difference in outcomes was left.

Modeling in test

Also in regard to Modeling in test the outcomes of the regression analyses did not confirm our hypotheses. However a trend in the expected direction was found. From the regression analysis presented in table 3 an 4 we learn that scores on the post-modeling test are predicted by the scores on pre-modeling test, vocabulary and the condition they were in (table 3). Although the model with all variables in it is not significant at the .05 level, it can be considered a trend that students in the experimental condition scored better than their counterparts in the control condition. Model 3 explains 31 % of the variance. Students with high scores on the pre-modeling test and vocabulary test scored better on the post-modeling test. Hence, the hypothesis that students in the experimental condition would score better on modeling, is confirmed. However, this can only be considered a trend. and depends on vocabulary and pre-modeling

Table 3. Regression analysis for variables predicting the scores on the dependent variable post-modeling (N=49).

Model	R Square	Std Error of the estimate	R Square change	F Change	Sign. F Change
1	.14	3.11	.14	7.71	.01
2	.27	2.90	.13	8.29	.01
3	.31	2.84	.04	2,64	.11

1 Predictors: (constant), vocabulary,

2 Predictors: (constant),vocabulary, pre-modeling

3 Predictors: (constant),vocabulary, pre-modeling, condition

Table 4. Coefficients of regression of the predictors on the dependent variable post-modeling.

(unstandardized scores)

Model 3	Unstandardized coefficient		Standardized coefficient		
	B	Std. Error	B	t	Sign.
(Constant)	-2.45	2,21		-1.11	.274
Vocabulary	.06	.03	.26	1.99	.053
Pre-modeling	.33	.12	.36	2.75	.009
Condition	1.80	1.11	.20	1.62	.111

Modeling of the product.

The final outcome variable, Modeling of the product, consists of the final model of the product, drawn by the students and rated by experts on modeling. It needs to be noted that these drawings were group products and the group scores were assigned to the individuals in their groups. In tables 5 and 6 the outcomes of the regressions analyses are presented.

Table 5. Regression analysis for variables predicting the scores on the dependent variable modeling 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

1 Predictors: (constant), age in months

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

Table 6. Coefficients of regression of the predictors on the dependent variable modeling of the product.

(unstandardized scores)

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

Model 2 in table 5 shows that 63 % of the variance can be explained by the predictors age and interaction variable age*condition. The variables pre-modeling and vocabulary were not significant. Younger students score better drawing the final model. The interaction variable predicts the score negatively (table 6). Although our final hypothesis, that students in the experimental condition produce better drawings, could not be confirmed, there was an interaction effect of age*condition. This means that younger students in the experimental condition had better scores on their final drawings as compared to their counterparts in the control group.

CONCLUSIONS AND DISCUSSION

This study explores learning in the workshop at school. In an intervention, students were to design and build a prototype of a tandem tricycle. In teams they worked on the design and met problems to overcome. In two conditions teachers helped them with those problems varying from very practical to theoretical. In the control condition the models to be used were provided as ready-made tools to solve the problems. In the experimental condition those models were designed and reinvented by the students themselves under active guidance of the teacher in a co-constructive way.

The hypothesis was: *students who participate as model designers in a process of guided co-construction show better learning outcomes as compared to students who learn to work with ready-made models.* Three research questions were formulated: as compared to students in the control group:

(1) do students in experimental condition acquire more knowledge in the domains of mathematics and science?

(2) do students in the experimental condition develop a better understanding of the use of models?

(3) do students in experimental condition produce better models/drawings of their own product?

The first question resulted in a negative conclusion. Analyses showed that there was no difference between the conditions regarding knowledge acquisition in the domains of mathematics and science. The second question regarding modeling could be answered in an affirmative way, though only as a trend. Students guided in a co-constructive way working on an authentic assignment have a better understanding of modeling. The third question resulted in an interesting outcome. Although our hypothesis, that students in the experimental condition produce better drawings of their final product, could not be confirmed, there was an interaction effect of age*condition. This means that younger students in the experimental condition had better scores on their final drawings as compared to their counterparts in the control group.

The evidence we have examined suggests that in the experimental condition students were better able to design models, both in the test and in their own final design of the product. In addition, in both conditions the knowledge acquisition was the same. By this we are led to the conclusion that guided co-construction as a pedagogy will have a positive effect on the learning outcomes of students in the workshops at school in vocational education.

The results from the present study show that the findings are only partly in line with other research on modeling. Van Dijk et al (2002) as well as Keijzer (2003) found that teaching modeling in a co-constructive way leads to better results in primary education. Doorman (2005) proposed that using guided reinvention when teaching modeling helps secondary school student to a better understanding of graphing change. Others (Jurow, 2005; McArdle & Ackland, 2007; Van der Sanden & Teurlings, 2003) have argued that learning from practical experiences, project based curricula or authentic assignments will improve the transfer of knowledge. Guile and Young (2003) are more critical and argue that for knowledge acquisition in a 'community of practice' participation only is not enough. Teachers should be giving explicit attention to relating situated knowledge and more general knowledge. In the intervention in this study the program was aimed at just that: moving from practical problems to mathematical and scientific modeling. Although there was no difference between our conditions, mathematical and scientific knowledge was gained in both conditions. As for modeling, a trend was found that students in the experiment conditions outperformed their counterparts in the control conditions.

From interviews we held with the teachers afterwards we noticed that especially the role of models differed across the conditions in the way they were used as an orientation tool. In the control condition the ready made models functioned mostly as explanation or as a construction plan. Whereas in the experimental condition the models were used to generate ideas and solutions. As MacDonald & Gustafson (2004) argue, this could mean that using drawings as open and multipurpose tools in a creative way leads to a better understanding of those tools.

Further research should be examining in a more qualitative way how models function as an orientation and communication tool in the workshop and how deeper understanding and knowledge acquisition depend on the guidance of the teachers (providing or co-constructing). Put differently: "How those tools are enacted in particular circumstances and activities is crucial"(Billett, 2001, p. 447).

Other notable suggestions from the interviews with teachers were that 'students just don't come up with mathematics' and ' [in the workshop] … there is hardly a relation between theory and practice'. Therefore, in the next design of the program there will be more attention for explicit teaching of theory derived from the practical problems.

The limitations of this study were the small scale and the complex environment. 55 students in two schools participated and not all of them were able to do all tests. Preparatory vocational education is a complex context for research. Students switch now and then from major, have different classes for different subjects, follow different trajectories and learning tracks and so on. In addition, the students have to deal with both subject matter teachers and practice teachers, of whom only some are able to cross those domains. Therefore it was not possible to develop a ready-made program for each condition and, as anticipated, the program for the teachers was subject of adjustment and change as they started using it. Consequently, the approach of formative intervention of Engeström (2008) turned out to be a good way to understand this process.

To conclude, the context of preparatory vocational education is rich and complex. Students learn while working on real-life assignments and as a result gain on knowledge and modeling. However due to the complexity of the environment we need to continue studying it and especially focus on *how* teachers and students use the models as tools for orientation.

REFERENCES

Barab, S., & Squire, K. (2004). Design-based research: putting a stake in the ground. *The journal of the learning sciences*, *13*(1), 1-14.

Biermans, H., Nieuwen, L., Poell, R., Mulder, M., & Wesselink, R. (2004). Competence based VET in the Netherlands. *Berufs- und Wirtschaftspädagogik -online*, (7). Retrieved February 10, 2009, from http://www.bwpat.de/7eu/biemans_etal_nl_bwpat7.shtml.

Billett, S. (2001). Knowing in practice: re-conceptualising vocational expertise. *Learning and Instruction*, *11*(6), 431.

Boersma, A., Ten Dam, G., Volman, M., & Wardekker, W. (2009). 'This baby…it isn't alive.' Towards a community of learners for vocational orientation. *British Educational Research Journal*, (1), 1-23.

Boersma, A., Ten dam, G., Volman, M., & Wardekker, W.'This baby ... isn't alive.' Towards a community of learning for vocational orientation. *British Educational Research Journal*.

Brown, A., & Campione, J. (1994). Guided discovery in a community of learners. In: *Classroom lessons: integrating cognitive theory and classroom practice*. Cambridge: MIT Press/Bradford books.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: theoretical and methodological issues. *Journal of the Learning Sciences*, *13*(1), 15-42.

diSessa, A. (2002). Students' criteria for representational adequacy. In: *Symbolizing, modelling and Tool use in mathematics education*, Mathematics Education Library (pp. 105-129). 30: Kluwer academics publishers.

diSessa, A. (2004). Metarepresentation: Native Competence and Targets for Instruction. *Cognition and Instruction*, *22*(3), 293-331.

Doorman, L. (2005). *Modelling motion: from trace graphs to instantaneous change*. Utrecht: CD-B press.

Engeström, Y. (2008). From design experiments to formative interventions. Utrecht: MIT press.

Goodlad, J., Klein, M., & Tye, K. (1979). The domains of curriculum and their study. In: J. Goodlad (Ed.), *Curriculum Inquiry*. New York, St Louis, San Francisco: McGraw-Hill Book Company.

Gravemeijer, K. (1997). Instructional design for reform in mathematics education. In: M. Beishuizen, K. Gravemeijer, & E. Van Lieshout (Eds.), *The role of contexts and models in the development of mathematical strategies*, Series on research and mathematics education (pp. 13-34). 26: CD-B press.

Gravemeijer, K., Lehrer, R., Van Oers, B., & Verschaffel, L. (2002). *Symbolizing, modeling and tool use in mathematics education*. Mathematics Education Library. 30: Kluwer academic publishers.

Guile, D., & Young, M. (2003). Transfer and transition in vocational education: some theoretical considerations. In: T. Tuomi-Gröhn & Y. Engestrom (Eds.), *Between school and work: new perspectives on transfer and boundary crossing*. Amsterdam: Pergamon An imprint of Elsevier Science.

Hill, A. M. (1998). Problem solving in real-life contexts: an alternative for design in technology education. *International Journal of Technology and Design Education*, *8*(3), 203-220.

Hirsch, E. (2006). *The knowledge deficit*. Boston: Houghton Mifflin.

Jurow, A. S. (2005). Shifting Engagements in Figured Worlds: Middle School Mathematics Students' Participation in an Architectural Design Project. *Journal of the Learning Sciences*, *14*(1), 35-67.

Keijzer, R., & Terwel, J. (2003). Learning for mathematical insight: a longitudinal comparative study on modelling. *Learning and Instruction*, *13*(3), 285-304.

Kolodner, J., Camp, P., Crismond, D., Fasse, B., Gray, J., Holbrook, J., et al. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design into practice. *Journal of the Learning Sciences*, *12*(4), 495-547.

Kozulin, A. (2003). Introduction: Sociocultural theory and education: students, teachers, and knowledge. In: A. Kozulin, B. Gindis, V. Agayev, & S. Miller (Eds.), *Vygotsky's educational theory in cultural context*. Cambridge: Cambridge university press.

Lave, W., & Wenger, E. (1991). *Situated learning: legitimate peripheral participation*. Cambridge: Cambridge University press.

Lave, W., & Wenger, E. (2005). Practice, person, social world. In: H. Daniels (Ed.), *An introduction to Vygotsky* (Vol. 2). East Sussex: Routeledge.

Lemke, J. (2000). Articulating communities: sociocultural perspectives on science education. *Journal of research in science teaching*, *38*(3), 296-316.

MacDonald, D., & Gustafson, B. (2004). The role of design drawing among children engaged in parachute building activity. *Journal of technology education*, *16*(1), 55-71.

Maes, M. (2004). *Vocational education and training in the Netherlands.* Cedefop Panorama series (Revised Edition.). Luxembourg: CEDEFOP (European Centre for the Development of Vocational Training). Retrieved February 10, 2009, from http://www.blackboard.uu.nl/@@06DE8A9E49CE8D30A6D5BACA5EE8F96B/courses/1/AIO_netwerk_BO/content/_304211_1/Cedefop_2004_Vocational%20education%20and%20training%20in%20the%20Netherlands.pdf.

McArdle, K., & Ackland, A. (2007). The demands of the double shift: communities of practice in continuing professional development. *Journal of Vocational Education & Training*, *59*(1), 107-120.

Mittendorff, K., Jochems, W., Meijers, F., & Brok, P. D. (2008). Differences and similarities in the use of the portfolio and personal development plan for career guidance in various vocational schools in The Netherlands. *Journal of Vocational Education & Training*, *60*(1), 75-91.

Rogoff, B., Matusov, E., & White, C. (1996). Models of teaching and learning: participating in a community of learners. In: R. Olson (Ed.), *The handbook of education and human development* (pp. 388-414). Oxford: Blackwell publishers Ltd.

Saxe, G., & Guberman, S. (1998). Studying mathematics learning in collective activity. *Learning and Instruction*, *8*(6), 489.

Sternberg, R. (1987). Most vocabulary is learned from context. In: E. McKeown & M. Curtis (Eds.), *The nature of vocabulary acquisition.* (pp. 89-106). Erlbaum.

Terwel, J., Van Oers, B., Van Dijk, I., & Van den Eeden, P. (2009). Are representations to be provided or generated in primary mathematics education? Effects on transfer. *Educational research and Evaluation*, *15*(1), 25-44.

The design based research collective. (2003). Design based research: an emerging paradigm for educational enquiry. *Educational researcher*, *32*(1), 5-8.

Van der Sanden, J., Terwel, J., & Vosniadou, S. (2000). New learning in science and technology. In: P. Simons, J. Van der Linden, & T. Duffy (Eds.), *New Learning: three ways to learn in a new balance* (pp. 119-140). Dordrecht: Kluwer Academic Publishers.

Van der Sanden, J., & Teurlings, C. (2003). Developing competence during practice periods: the learner's perspective. In: *Between school and work: new perspectives on tranfer and boundary crossing*. Amsterdam: Pergamon An imprint of Elsevier Science.

Van Dijk, I., Van Oers, B., & Terwel, J. (2003). Providing or designing? Constructing models in primary maths education. *Learning and Instruction*, *13*(1), 53-72.

Van Dijk, I., Van Oers, B., Terwel, J., & Van Eeden, P. (2002). *The learner as a designer: effects on transfer of an experimental curriculum in modelling*. Enschede: Ipskamp.

Van Oers, B. (2001). Educational forms of initiation in mathematical culture. *Educational Studies in Mathematics*, *46*(1), 59.

Van Oers, B. (2006). An activity theory approach to the formation of mathematical cognition: developing topics through predication in a mathematical community. In: J. Maasz & W. Schloeglman (Eds.), *New mathematics education research and practice* (pp. 97-141). Rotterdam: Sense Publishers.

Van Oers, B., & Wardekker, W. (2000). De cultuurhistorische school in de pedagogiek. In: *Pedagogiek in meervoud* (pp. 171-213). Houten/Diegem: Bohn Stafleu Van Loghum.

Van Schaik, M., Terwel, J., & van Oers, B. (2009). Towards a knowledge rich learning environment in pre-vocational secondary education. *Submitted*.

FIGURES:

Figure 1: first drawing of the design of a group in the control condition.

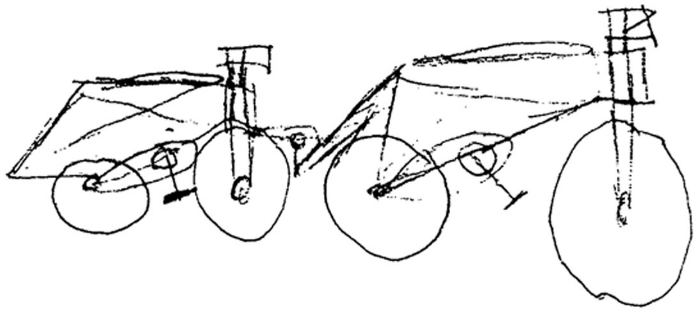
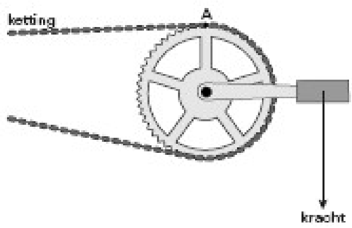


Figure 2: The winner tricycle of the competition chosen by the jury of experts

Figure 3: 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 bigger than on the pedal.

Figure 4: Drawing item in test

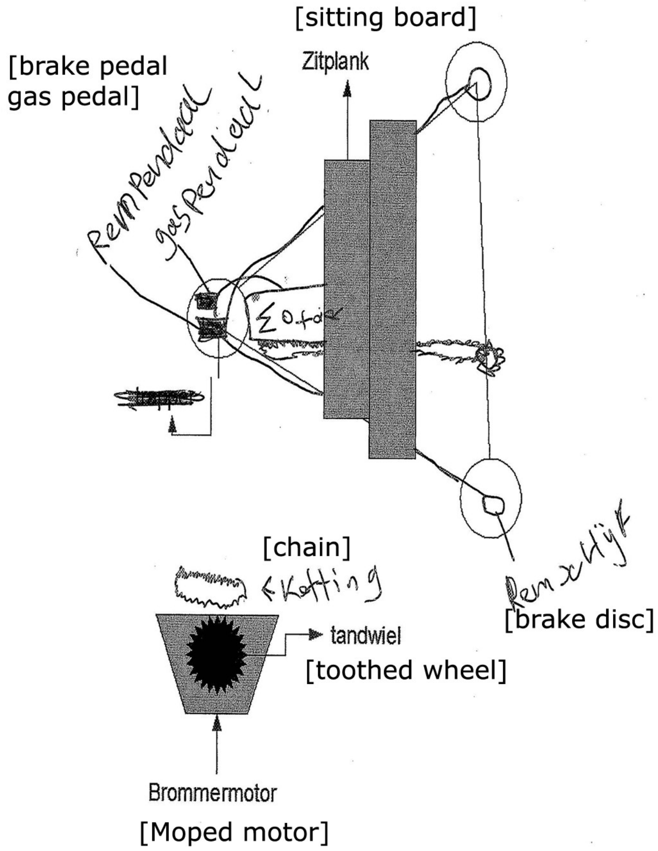


Figure 5: Final drawing of the product of a group in experimental condition.