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Towards a knowledge-rich learning environment in preparatory secondary education

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In this case study a novel educational programme for students in preparatory vocational education was studied. The research questions were: (1) Which teaching/learning processes occur in a simulated workplace using the concept of a *knowledge-rich* workplace? (2) What is the role of models and modelling in the teaching/learning processes? The curriculum project consisted of design and construction tasks. The students were collaboratively involved in the process of designing a tricycle for a real customer. This real-life activity creates opportunities for students to develop and use models, which can be used in more than in one context. The case study explored how the teachers deal with the students' explicit and implicit need for knowledge and skills. The main findings are that teachers more often provide this knowledge, rather than guide the students in reconstructing it, and towards the end of the project, knowledge tended to remain situated.

Learning in preparatory vocational education

Over recent decades, Dutch preparatory senior secondary vocational education (VMBO)[1] has gone through radical changes. Traditionally, this education was mainly focused on training technical and vocational skills. However, in the 1980s, theory-based learning became the focus in VMBO. Neither of the two approaches was satisfactory. The first (practical) approach could not optimally stimulate the broad development of students, while the second approach was often too difficult or resulted in meaningless mechanical learning.

Within the European Union and elsewhere it is recognised that in order to prepare students for the demands of the future, they should obtain competencies that cover both broad general knowledge as well as technical skills (Commission of the European Communities, 2008; Cedefop, 2009). However, there is an ongoing

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debate on how to connect formal learning and learning in the workplace (Billett, 2003; Guile & Griffiths, 2001; Tuomi-Gröhn & Engeström, 2003; Griffiths & Guile, 2004).

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

Real workshop activities could increase the need for specific knowledge and skills and subsequently provide opportunities for learning. Following Guile and Young (2003), such a workplace can be characterised as a 'knowledge-rich workplace' (p. 73). Knowledge-rich workplaces are assumed to engage students in meaningful activities and at the same time promote subject matter learning (like mathematics, see Kent *et al.*, 2007).

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

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

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

Models and modelling in knowledge-rich practices

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

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

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

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

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

Although there are many different definitions of models, the definition by Van Oers (1988) is used in this article. Van Oers stated that 'a model can be described as any material, materialised (for example a graphical display) or mentally pictured construction, built up from identifiable elements and relations, which structures the user's actions' (p. 127). Models function, in education as well as in science, as tools in a problem-solving activity and are important in both individual and social cognitive processes (Van Oers, 1988, 1998). The key issue here is that models contain assumptions about reality and about the relationships between the model and the represented reality. It is not necessary to assume that models exactly copy reality. Rather, functional models only assume that the outcomes of (possibly mental) actions on the model correlate in an actual way with the outcomes in reality, if the same actions were performed in reality. For example, a drawing of a bike on a scale of 1 to 10 assumes that relations and ratios in reality are maintained as scaled in the drawing. The models in various problem-solving activities, in our case the process of designing and constructing a tricycle, differ in the number and content of the theoretical assumptions. Students need to know the assumptions in order to understand or create a model. This is how models can function as tools for knowledge (re)construction. The kind of models and modelling required in a setting contributes to the knowledge-richness of a learning environment.

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

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

Different types of models can also be distinguished. A rough distinction can be made between *canonical models*, which represent a structured body of knowledge in symbolic form, and *situated models*, which represent personal or setting-bound images of a situation. In Figure 1, (a) represents a canonical (i.e. in Guile and Young's terminology 'disciplinary') model of a straight line, while (b) represents a situational model. Characteristic of situational models is that they are mainly evaluated on their functionality in the situation given, or the problem at hand (Van Oers, 1988). Thus, to create a knowledge-rich environment for modelling, codified or disciplinary models should be brought to bear in the community of practice in which teacher and students work together.

From the distinctions above, it can now be determined whether a learning environment can be considered knowledge-rich or not. An environment is considered knowledge-rich when it has the potential for students to acquire knowledge that is codified or disciplinary. In other words, knowledge-richness depends on the possibility of an environment that may bring students from situated and tacit knowledge and models, to codified and disciplinary knowledge and models. In the case of technical education, that means, for example, that students do not use Pythagoras'

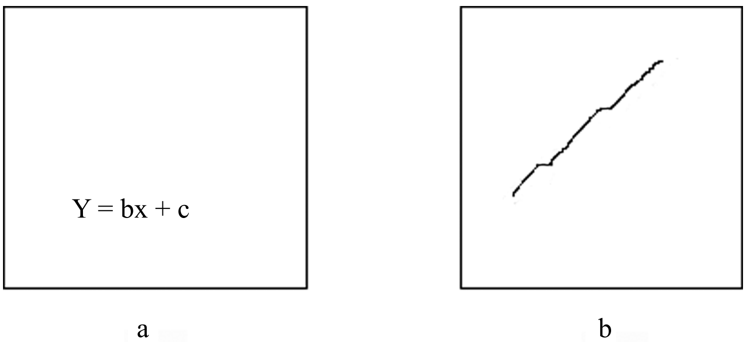

Figure 1. A canonical (a) and a situational model (b)

rule for calculating the length of a piece of steel only once, but that they also understand it as a mathematical model that applies to a range of situations; that it is a tool in the discipline of mathematics which has practical and theoretical use.

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

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

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

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

Method

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

Curriculum project

During a period of 12 weeks, students (aged 14–16 years) had to choose what to design and construct, in subgroups of three or four for a 'real' client: a tandem tricycle or a bicycle game. The clients were a primary school principal and the owner of a party centre who were willing to buy the final products. Working for those clients provided a basis for the students' 'prolepsis' during the design process, as in order to satisfy the clients, the students had a real interest in the quality of their final products. Initially, the assignment for the students was formulated in just a few sentences:

> Please design and build:
>
> (a) one tandem tricycle made from two tricycles for children who are four to five years old, so that the children have to cooperate;
>
> (b) an indoor bicycle game, with two bikes on rollers which race each other, and includes a display of who is winning.

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

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

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

Research situation and sampling

For this first phase of the project, one school in the middle of the Netherlands was selected that had been working with assignments like the ones described above. With a team of teachers, the project was implemented in a workshop which was a simulation of a genuine working place. The workshop was situated in the school. In the workshop students worked with big machines and genuine workplace equipment such as welding tools and lathes. Together with the team of teachers we decided to separate out the design part of the 'achievement'[2] from the construction part. In that way, students first received an assignment to design (on paper) a tricycle or a bicycle race game. Second, the team with the best design, chosen by a teacher jury, was allowed to build the product. The designing took place during a series of four mathematics lessons in the open learning centre next to the workshop. Students were able to use computers to search for information and to ask the mathematics teacher for help. After that, the construction of the products was done during the vocational lessons in the workshop under the guidance of the vocational teacher.

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

For this case study we followed two teams of students who were allowed to build their design. Six boys in two teams of three worked separately on their assignment. Team A was formed by one student (Ryan) working at the lowest level (basic level) of the VMBO and two (Sander and Alim) working at the second level of the VMBO (staff level).[3] Team B consisted of Joost and Mohammed (both basic level) and Raoul (staff level). Our unit of analysis were the subgroups and their teacher and their ways of participation in the classroom practice.

Data collection and procedures

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

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

Pattern analyses

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

First, two observers commented on all the video material using the comment function in the Noldus software. Next, the video was viewed again, now coding the activities that seemed to enrich the learning. If necessary, comments were adjusted or added. An activity (i.e. an 'event' in Noldus[4]) was coded as *enrichment* when it produced new information or knowledge on the basis of problem solving with the help of theory or general rules. In other words, *enrichment* occurred when tacit knowledge became explicit, or situated knowledge was transformed into codified knowledge. For example, calculating the length of a piece of steel with the help of Pythagoras' rule was coded as enrichment, whereas practising welding was not. One hundred and eighty-eight out of a total of 237 events were coded as enrichment. The observers agreed on 89% of the enrichment codes (Kappa = .72). Finally, all comments and codes of the two observers were brought together in order to formulate the patterns. For triangulation we explained those patterns to the team of teachers in a second member check session. They recognised all the patterns and agreed that the patterns were typical for their teaching practice.

Results: three patterns

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

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

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

1. Introduction. In one of the first weeks of the curriculum project, Mr Williams, the technology teacher, was heard saying, 'Let your mind work', three times in one lesson. It seemed to be an encouragement for the students to think. However, the students were given a task they had to perform at home, or in the mathematics classes. Hence, some deeper thinking in the practice workshop can occur, but when students did not come up with solutions or answers fast enough, they had to find them elsewhere. Moreover, we can see that the teacher made an effort in teaching the students more than just the situated knowledge needed for the solution of a particular problem. In the beginning of the construction process, the teacher often referred to mathematics or he explained rules and possibilities in general. However, as the actual construction process proceeded and the teacher and students had less time, and the more situated and tacit the knowledge remained for the students, the less the teacher explained and tended to 'give away' or provide the solution to the students. This means that the students received increasingly tailored solutions and 'tips and tricks'. In the workplace, time is scarce, so deeper thinking that takes more time has to be done outside the workplace, or, later on in the process, solutions are simply *provided* by the teacher.

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

Excerpt 1.1

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

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

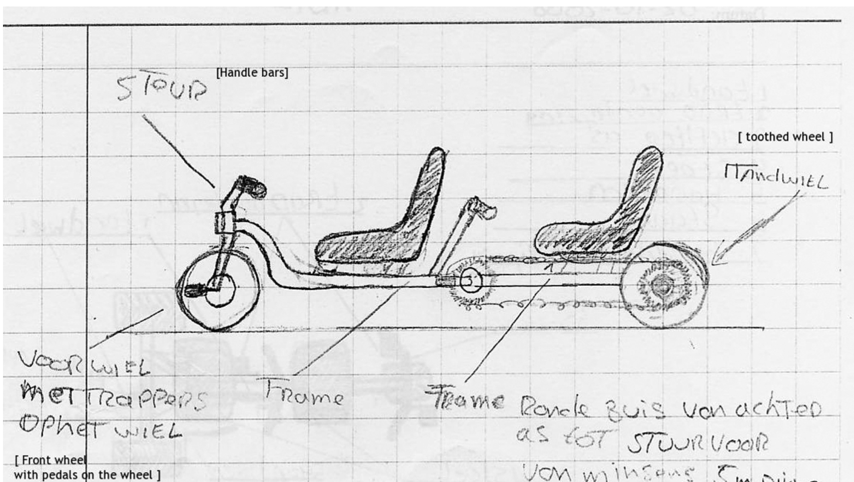

Figure 2. First draft of design of tandem tricycle drawn by students

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

Excerpt 1.2

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

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

Excerpt 1.3

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

Later on in the process, in week five, the teacher finds a problem concerning the position of the crank. The teacher, in his role as a member of the design team, has to look again at the technical drawing (Figure 3) he made:

Excerpt 1.4

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

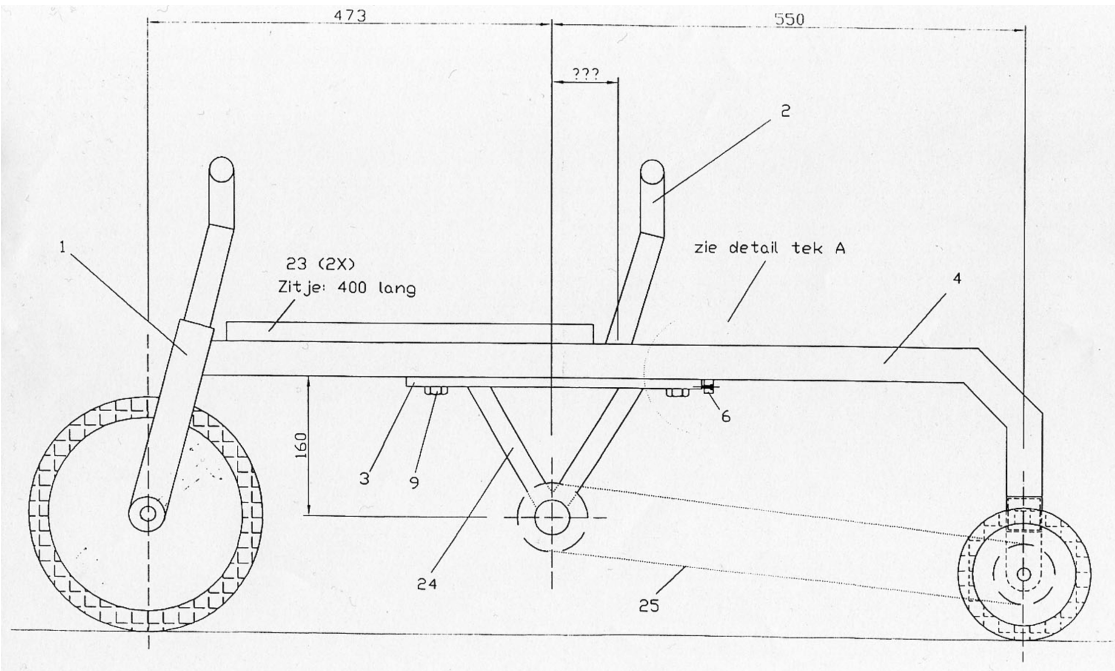

Figure 3. Technical drawing of students' design drawn by the teacher

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

Excerpt 1.5

Sander:	Why do there have to be holes in the tube?
Mr Williams:	Because if water runs in, it has to come out.

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

Excerpt 1.6

Mr Williams: I think it is my job to get the project started well. I have tried it before, waiting until the students came up with their plans. But before you know, a week has passed and then the plan of the project ends up in a folder or so.

…

If I didn't do anything, in the end a pedal will be welded somewhere randomly, a chain spanner forgotten and those kinds of things. There will be a product in the end, but I would not want to have it sent out to the client.

…

Let alone that they [the students] have to make a construction drawing, they are simply not up for it. The drawings and sketches they make do not resemble a technical drawing. It think that it is my job to make a drawing they can work with.

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

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

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

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

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

Excerpt 2.1

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

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

Excerpt 2.2

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

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

Excerpt 2.3

Mr Williams: When you have an equation with only one missing variable, you can calculate that variable. Can you do that?
[*Students try, randomly, some figures.*]
Ron: Oh, euh, a + b = c
Mr Williams: No, that's not what it said; c square = a square + b square.
[Finally one of the students comes up with the solution to take the square root.]

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

Excerpt 2.4

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

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

Pattern 3. A workplace simulation is stimulating

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

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

Excerpt 3.1

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

When the group presents their product to an audience of students and teachers, they cannot stop talking about the solutions they have found. Their presentation takes more than 20 minutes, whereas presentations generally take about 10 minutes.

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

Excerpt 3.2

Ryan:	So we thought of doing it like this. …
Mr Williams:	But then you'll have the problem that the tricycle will not turn easily …

Ryan intervenes:	Then we need to have one free wheel
Mr Williams:	Exactly!

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

Excerpt 3.3

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

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

Excerpt 3.4

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

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

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

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

Conclusion and discussion

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

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

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

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

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

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

Notes

1. In this article, we use the Dutch acronym (VMBO) for preparatory senior secondary vocational education. VMBO is Dutch secondary education for students aged 12–16 years that prepares them for senior secondary vocational education. Sixty per cent of all Dutch students aged 12–16 years attend VMBO (Maes, 2004).
2. The school's term for assignments.
3. Dutch preparatory vocational education has four levels/tracks: basic, staff, theoretical and mixed staff/theoretical. Students are graded according to their level. Students in our study worked in heterogeneous groups of basic and staff level.
4. In Noldus Observer XT an event is coded; a series of events is an episode.

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