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Representations in simulated workplaces

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Abstract In vocational education students are to be prepared to participate in communities of practice. Hence they need technical skills as well as content knowledge e.g. science and mathematics. Research has shown that the instructional strategy of guided co-construction may lead to deeper understandings within a practice. The research questions in this article aim at finding out whether guided co-construction is an effective strategy in joining experience and general knowledge with representations as tools for communication and orientation. The present study is a qualitative analysis of a design-based research project. Our goal was to establish how the use of representations developed within a process of tandem tricycle construction. We looked for video data that could potentially explain how representations were used in practice and how such use was related to vocational and academic disciplines. Interesting differences could be revealed which were clearly related to differences in the way representations were designed and used in the whole cycle of problem solving (the construction of a technical object). At two of the four schools the representations remained visible and continued to be used until the end of the process. Designing and using representations as a core activity in vocational education could be the key to integrate theory in designing and constructing in the workshop.

Keywords Vocational education · Representations · Design · Theory and practice relationship

In workplace simulations in vocational education students often work on real customer assignments and products. As found in previous studies (e.g. Schaap et al. 2014) the process focuses first on timely delivery, second on the acquisition of necessary skills and

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only in the last resort on the development of understanding. In this article we argue that designing and using representations creating a technical artefact should be regarded as the pivotal activity during practical assignments by which the understanding and integration of general curriculum subject matter can be enhanced. The general curriculum subjects focussed on in this study are mathematics and science. An instructional design that has students' designing as a pivotal activity may create opportunities for, as Reisslein et al. (2010) put it, a "transition from contextual problem representations to abstract representations" (p. 233). This transition is an example of vertical recontextualization. In our case, students understand a representation they use in a practical context also as a concept or tool that can be of use in another more theoretical context: a general curriculum subject such as mathematics (Guile and Young 2003).

In this article the representations in question are firstly the students' sketches, drawings, scale models. Secondly, also more formal models from the vocational discipline (e.g. construction plans and design drawings) and science and mathematics (e.g. formulas, conceptual models) are taken into account. The instructional design is meant to support students to recontextualise their understandings and skills from the first to the latter, and vice versa. We will argue that when the pivotal activity of students in a simulated practice is the designing, the learning processes of the related formal content knowledge will be enhanced, which in turn will result in a deeper understanding. The students in this study follow a curriculum that has both general and a vocational aims with a technical focus. The programme can be considered an interdisciplinary course in which they are prepared for secondary vocational education in a specific technical or technological domain.[1] Characteristic for the schools in this study is that they use engineering and design assignments for the students to introduce them to several technical disciplines.

In vocational education students are to be prepared to participate in communities of practice. For the students these communities are simulations at school. However, these communities also represent the actual vocations that are simulated. Students need to develop skills and knowledge that are applicable in their future practice, as well as learn to recognise when and how to apply these in practical situations. Introducing students to certain sociocultural practices (e.g. workplace *as well as* mathematical practice) is best described as a process of legitimate peripheral participation (Lave and Wenger 2005). In such a context, learning may be seen as a process of qualitative change in activities, resulting in enhanced possibilities of sociocultural participation (Van Oers and Wardekker 2000). Such enhancement also contributes to *enculturation* into a community of learners (Brown and Campione 1994; Lemke 2000).

When learning takes place in a simulated workplace setting at school, the agents involved (students and teacher) may be characterised as a *community of practice* (Lave and Wenger 2005). In such communities the participants share basic assumptions regarding the community's rules and purposes. As learners they are actively involved in meaning-making activities, as well as in problem solving. Using tools and artefacts they communicate with each other as well as with others outside the community. As Roth and Lee (2006) have pointed out, in schools classrooms cannot be called communities of practice if they do not have a shared object and a division of labour. However, in this study the subgroups of students do have a shared object (i.e. designing and producing an artefact) and do have a division of labour. It is a simulation of a community of practice in a vocation.

[1] VMBO in the Netherlands is preparatory secondary education with a vocational perspective. See Cedefop (2009), Maes (2004) and Van de Velde (1991). In this article vocational education refers to VMBO.

When prepared for a vocation, students should become competent in the various modes of understanding in a discipline or in a particular practice, and develop a *disciplined perception* (Stevens and Hall 1998). As Stevens et al. (2008) point out, in education the disciplinary knowledge is represented in 'problem sets and exams' (p. 357). However, in those sets the knowledge used by professionals is not well reflected, since the sets are not the performance contexts in which the disciplinary knowledge is accounted for in the everyday practice of professionals. In vocational education[2] representations in the context of a practice (including disciplines) need to be understood and used as conceptual and strategic tools in relation to present and future problems typical for that practice. In simulated workplaces in vocational education the disciplines can be both academic and vocational. The first in the form of general curriculum subjects, derived from academic disciplines such as mathematics and science. The latter are in our study the technical domains. The present study involves an analysis of how students are guided by the teacher and learn to understand and apply codified knowledge from the vocational and the academic disciplines (cf. Kilbrink and Bjurulf 2012).

The present study is an analysis of the qualitative data of a third iteration design-based research project (Bell 2004; Cobb et al. 2003; Collins et al. 2004), although it might also be described as a 'learning study' (Marton and Pang 2006; see method section).

Previous studies in our project have shown that designing and constructing a real product in preparatory vocational secondary education (VMBO) has the potential of being knowledge-rich and improving the understanding of mathematical and scientific concepts. A learning environment was regarded knowledge-rich, when students had the opportunity to understand and apply codified knowledge (Guile and Young 2003) and could have experiences that supported "… development of deep understanding organised around key concepts and general principles…" (Litzinger et al. 2011, p. 126). Since the outcomes of previous research were satisfying with regard to how representations were used by students in their design activities (Van Schaik et al. 2010a, 2011), in the present study we will look more closely at how students use representations in their design activities and how this relates to both vocational and academic disciplines. We need to look at the classroom micro level in order to find the key determinants that might lead to using representations in the school workshops that resembles the practice of professionals. For this purpose we used the data of our latest experimental intervention to conduct a qualitative analysis, in order to discover more details about the students' use of representations under different classroom conditions. We aimed, first, at finding out in general the ways in which the research designs were implemented at every school. Our next goal was to establish how the use of representations developed micro-genetically within a process of tandem tricycle construction (see method section), and whether it was effective in joining experience and general knowledge, as codified in the general curriculum. The following two questions arose in the process:

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

[2] In vocational education (especially pre-vocational education) generally students are educated for a vocation while also being taught more general knowledge.

Representations as tools in the practical design process

In design education, drawings and representations often only serve to plan or represent the product to be constructed. By contrast, in professional design processes representations and drawings also function as thinking tools to generate ideas and to communicate proposals (MacDonald and Gustafson 2004). This is in line with our view that representations are symbolic means that articulate relevant elements and their interrelationships of an object to be studied, and as such serve as efficient tools for orientation and communication (Van Oers 1988). We follow Tuomi-Gröhm and Engeström (2003) who state that representations can be used first to reflect on past processes and subsequently to negotiate a possible direction for their future activity. For example, in vocational education a draft representation of a tricycle is a reflection of the student's efforts to design a product that is to be constructed. It enables the makers to use the representation to show where their design process had taken them up to the point of examination and to discuss or explain their solutions to others. Moreover, the representation functions as a plan for future action: it *is* the construction plan. A representation—by definition—reveals an object to be studied in a reduced way and articulates its crucial elements and their interrelationships. Due to the nature of such representations they can also serve as plans for actions, that is, a tool for collaboration, or more precisely: collaborative communication and orientation.

In our view, precisely these functions of representations can bridge the gap between practical problem solving and the codified knowledge present in the curriculum. In the case of designing a tandem tricycle, for example, student construction plans can function as representations that represent both the state of the design process and the students' orientation on their future activity. Such a plan could, for instance, constitute a reference to the desired length of components. It can also be a tool to anticipate practical problems, for example, the correct order of construction. At the same time, in order to appreciate the applicability of the representation, students need to see the principles behind the representation. They need, in other words, a *disciplined perception* (Stevens and Hall 1998). 'Disciplined' implies both *practised* and understood *as usual in the discipline*. The students have practised, trained and acquired the way practitioners in the field use the representations. At the same time they have understood the disciplinary concepts, strategies, rules and principles. In the case of vocational education the disciplines being both vocational and academic. The first involving domain specific knowledge and skills, 'accountable disciplinary knowledge'(Stevens et al. 2008), the latter involving the general curriculum. In other words, students develop a disciplined perception when they learn to see the applicability of their concepts and skills in the situation given. When students draw representations on the basis of rules on how to depict various views of their design of, for example, a tricycle, they require a mathematical understanding of ratios, scales and so on. Moreover, in order to develop a strategy in the disciplinary practice of designing useful representations, students need to know how to calculate angles and distances, in ways other than just guessing or drawing to scale. Knowing-how in this sense requires understanding codified knowledge.

In recent publications, based on cultural-historical theory, the concept of boundary object is used in a way similar to the way we view representations in simulated workplaces (Kent et al. 2007a, b; Akkerman and Bakker 2011a). The boundary in our case is twofold: it is between the simulated and actual workplace and it is between practical problems in the workplace and the theoretical (codified) knowledge to solve those. Representations can be a tool to bridge those boundaries (Schaap et al. 2014). The learning mechanisms involved in our case would mainly be reflection and also transformation. Especially ‘perspective taking’ can be enhanced by collectively reflecting on representations (Akkerman and Bakker 2011b). This occurs when the understanding and the perspective of a concept or problem become explicit.

These processes of collaboration and negotiation to develop a deeper understanding are neither unguided nor minimally guided processes. The teaching strategy is better described as *guided co-construction* (Hardman 2008; Mercer 1995). Guiding in a co-constructive way means helping students to collaboratively reconstruct models and subject matter knowledge through an on-going and reciprocal discursive process, focused on the solution of task-related problems.

Guided co-construction is a socio-cultural view on teaching based on the theory of Vygotsky (Hardman 2008). It takes a situative perspective on learning (Johri and Olds 2011) and suggests that learning does not take place through the addition of discrete facts to an existing store of knowledge. From a socio-cultural perspective learning occurs when new information, experiences and ways of understanding are related to an existing understanding of the matter in hand. One of the most important ways of working on this understanding is through talk, particularly where students are given the opportunity to assume greater control over their own learning by initiating ideas and responses (Hardman 2008, p. 254).

A teaching strategy within a guided co-construction approach is scaffolding. We follow Van de Pol, Volman and Beishuizen (Van de Pol et al. 2011) viewing scaffolding

> … as the temporarily contingent (i.e. being responsive to the current level of the student) support provided by a teacher to a student during the performing of a task which the student might otherwise not be able to complete. To realise such support, the teacher temporarily takes over parts of the student’s task with the goal of transferring the responsibility for the task back to the student at a later point in time (p. 46).

Especially contingency and the transfer of responsibility are key characteristics of guided co-construction.

Research has shown that the instructional strategy of guided co-construction may lead to better understanding of mathematics and modelling than a strategy based on simply providing ready made models as solutions to problems (Doorman 2005; Terwel et al. 2009; Mercer 2002). Mercer gives the following summary of the characteristics of teachers who were successful in supporting pupils in their development of mathematical problem solving and reading comprehension. Such teachers use questions “not just to test knowledge, but also to guide the development” (Mercer 2002, p. 144). They also taught more than just subject content. They helped students understand the problem-solving strategies and make sense of their experiences. Finally, “they treated learning as a social, communicative process” (Mercer 2002, p. 144). All of these characteristics are elements of what we call guided co-construction. In contrast to a ‘providing’ form of teaching in which knowledge, concepts and models are presented as ready-made solutions, guided co-construction may lead to a better understanding of the process of designing representations itself.

Roth (1996) formulated implications for learning environments, as the one in this study, in which designing is an instructional tool as well as the goal of the instruction. From our own earlier findings, the implications formulated by Roth and the theoretical framework explained above, we have designed our intervention.

Method

From findings of earlier studies in our project we developed an instructional design that was implemented a number of experimental schools. It consisted of a student assignment and an instructional tool for teachers. Our intended design was adjusted together with the teachers to their local conditions, helping us to do justice to the school context and helping the team of teachers to understand our aims. The present study is the third iteration of a design based research project (Bell 2004; Cobb et al. 2003; Collins et al. 2004). However, since not everything of the design was in the hands of the researchers, and the goal was not to try to 'cover as many variables as possible', the study also complies with the features of a 'learning study' (Marton and Pang 2006, p. 196).[3] The unit of analysis in this study is the subgroup of about three to five students, with teachers present in the classroom in the context of their school.

The largest part of the data in this study consisted of video observations and interviews, all gathered during our earlier studies. Together with students' representations, drawings and other process data, the data were analysed on the basis of a 'whole to part' approach, meaning that analyses started with reviewing and tagging video at school level, after which a microanalyses of student–teacher interactions was performed at classroom level (Erickson 2006). The results of a previously analysed study (Van Schaik et al. 2010b) didn't give satisfying insight into the precise use of representations by students. This stimulated us to conduct new qualitative analyses on the basis of case studies. Thus we analysed the existing data on how it could potentially explain how representations were used in practice.

The schools in the study were originally assigned to two conditions. Similar in both conditions was the assignment for the students and thus the potential opportunities for teacher guidance towards disciplinary knowledge. The main difference between the conditions was the openess of the teaching: a guided co-construction approach in the experimental condition versus a 'providing' approach in the control condition (Van Schaik et al. 2011). In both conditions teachers were trained and had a guiding instrument (see below). However in the following qualitative analyses all schools will be regarded as separate cases. We looked for ways in which representations function in classroom interactions and how teachers guided the design process. The main focus of analysis was to find the key determinants of teaching/learning strategy at classroom level that supports students' use of representations as tools.

Participants and setting

Schools for preparatory vocational senior secondary education (VMBO) educate students with a dual perspective: general-theoretical and vocational (Cedefop 2009; Maes 2004; Van de Velde 1991; Vries 1992). Students are between 12 and 16 years old and are prepared for secondary vocational education in both general subjects as mathematics and languages as well as vocational disciplines such as mechanical engineering.

87 students from the final two grades at four schools participated in the study. They worked on the tricycle assignment in subgroups of three, four, or five (all male,[4] mean age 16.06 years). At all schools the teachers were responsible as a team for a larger group of students, which often included the participating students. In total 12 teachers participated. The students worked most of the time in a workshop setting, where computers and

[3] For more discussion on design based research see Engeström (2009), Engeström and Sannino (2010).

[4] As in other countries mostly boys choose to follow a technical vocational programme.

technical equipment were available. Some schools used a separate classroom for instruction and/or computer designing (see below). Since the way in which the school adapted the intended curriculum design was part of our analyses, detailed descriptions on how the intervention was enacted are reported in the results section.

Schools

Since the unit of analyses in this study is the subgroup of students in the setting of the school, we start with a description of the context of the schools. Schools 1 and 2 were initially assigned to the experimental conditions, school 3 and 4 to the control condition. Although condition is not the explanatory variable in this study, we mention it here since the guiding instrument the teachers use differs (see below).

School 1: Peter Willems College[5]

This school had 33 students in 11 groups of three working on the project. Students worked in a central workplace area with a computer room in the middle and two classrooms on the side, where they went for theoretical lecture-based instruction. Sometimes the computers were used for information searching. Most of the time a single senior teacher guided and graded the students. Other teachers and classroom assistants helped students with practical problems.

School 2: Technical College Oldenhave

At school 2 four groups of four students out of a class of 24 chose to work on the assignment (two other groups were working on other authentic assignments). Students worked in two spaces: one, their 'homebase', with computers and various forms of technical equipment, and one for the metal work (welding). A team of four teachers, subject matter as well as practice teachers, guided the students.

School 3: Prince of Orange College

At school 3 five groups of four or five, 23 students in all, worked on the assignment. Students worked in a open workplace with technical equipment and computers available. The subject classes were held in a different part of the school building, taught by non-practical teachers. The workshop space was one of the corners of a 'practice square' with all vocations having their own corner and a central teacher's office in the middle. Computers were available, as well two smaller instruction rooms.

School 4: Orthen Technical School

This school had 15 students working in five groups of three. The workshop space had recently been refurbished. Computers and a separate instruction space were available. Students were guided by both two practical teachers and one teacher who taught prototype lessons. The latter was also a practical welding teacher for the project students. The teacher in question had formerly been a teacher of mathematics and physics. Computers with 2D-CAD software were used for the drawings.

[5] The names are not the real names of the schools, but pseudonyms

Materials

Assignment

For the student the assignment was the following:

> Design and construct a prototype of a tandem tricycle for children aged 4–7 in such a way that the children have to cooperate.

The assignment was placed in the context of a competition among peer students. The prototype competition created an opportunity to have the students explain how they would produce more than one tricycle for a jury. This created a rather realistic industrial design simulation and the existence of an expert jury linked the assignment to an actual practice. In addition, one of the requirements was the production of a representation on paper of the final product as it was actually constructed.

The students had to design and construct the tandem tricycle in a 10-week period, during which they worked at least 2 h a day in the workshop setting and in open classrooms in which computers were available. In both spaces teachers were available for questions and guidance. The design process was reflected on during workshop hours or in lessons or sessions separate from the workshop and the construction process (the prototype lessons). During workshops mainly practical problems were encountered, which were most of the time directly solved or redirected to separate lessons. During the latter periods teachers offered guidance in problem solving, using the students' own designs as well as the relevant subject matter in science and mathematics. Representations were used either in a providing way or in a co-constructive way: respectively supporting students with ready-made representations as solution to problems, or guiding them in constructing their own representations. For the students, the process started with an introduction by the researchers explaining the purpose of the assignment, namely the construction of a prototype to win a competition. During the next week the students started designing (see Fig. 1 for an example) and moved on to construction in the weeks following. The competition ended in the first instance with the selection of the two best prototypes at each school, followed by a final adjudication with a jury deciding on the winning construction (Fig. 2).

Guiding instrument for the teachers

A teacher manual was developed which consisted of explanatory notes to the assignment and the possible problems that students might encounter. The manual differed according to the way students in the two conditions had to be guided. For the experimental condition a template for ad hoc lessons and instruction was designed in the manual, and possible content for those prototype lessons was explained. The manual for the control condition consisted of an actual lesson plan with spelled out mathematics and science concepts.

In both conditions the schools decided when to start and end the project, within a range that fitted within their annual planning. Students worked on the assignment at least 2 h a day during a 9–11 week period. Teachers were not trained for the project, since it was adjusted to their specific conditions.

Instruments and procedures

The main source of data for the present analyses was the video data consisting of classroom observations and interviews. Video was collected using a three camera approach, with two

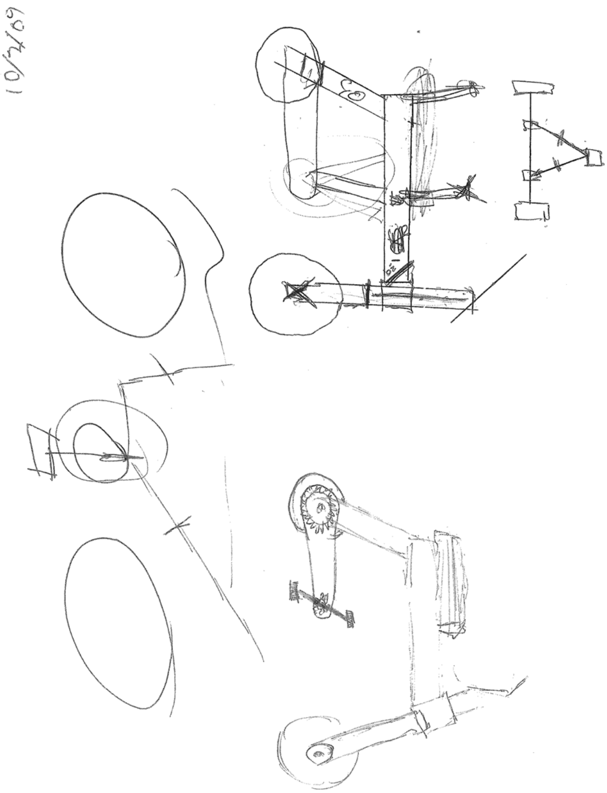

Fig. 1 First sketch of a tricycle from students at school 1

Fig. 2 Picture of the winning tricycle

fixed cameras recording opposite angles of the whole classroom and one hand-held camera recording the interactions and activities from closer by (Van Schaik 2009). Video was collected at schools at least at three and at the most at five moments during the process, depending on the planning of the schools. Recording sessions (video observations) ranged 60–266 min per session (see Table 2). The video data were loaded into computer software (Noldus 2009), and the video streams from each camera were viewed simultaneously.

Analyses

Analyses of quantitative data in a previous study (Van Schaik et al. 2010b) showed that no significant difference could found between the two initial conditions on post-test scores and no school from either one of the conditions differed significantly from the others. The main focus of the present analysis was finding out how the educational designs were actually implemented at every school. Initially, we expected that the experimental schools would outperform the controll schools in students' understanding of the disciplines, in line with our theoretical assumptions that guided co-construction leads to better understanding. Since this was not the case, measured by scores on the post-tests, our goal was now to establish how the use of representations developed micro-genetically within a process of tandem tricycle construction. And subsequently, whether it was effective in joining experience and general knowledge, as codified in the general curriculum. Therefore we mainly used the observational and interview data. All products, drawings and other artefacts were considered in the context in which they appeared. The representations that appeared in the observations were classified according to three categories, initial sketches, elaborated and refining drawings, and final and presentation drawings. According to MacDonald and Gustafson (2004) these are the types of drawings professionals use in their design process. Table 1 shows the categories and the clues by which they were established. We used the clues and categories for the representations we found in the observations.

We took project week 6 as the starting point for analyses of the school observations and from there we conducted analyses of the other weeks. Week 6 was the week in which we expected, on the basis of previous studies, that the students were at a stage between designing and construction. At that point the designs and drawings were in a final state, and could have become tools in the construction process as a means to accomplish the collective goal of tricycle construction. From our previous studies we also knew that by that time students are at the point where practical design problems occur. Then, for example, they find out that some of the tricycle parts cannot be constructed as planned, due to the absence of certain machines or unavailable materials. Solutions were often purely pragmatic and based, for example, on availability of materials. Sometimes the original construction plan had been discarded. This was anticipated in the present study by including one demand in the assignment to the effect that a final drawing had to be of the product 'as constructed'.

Project week six was observed at all schools; the moments of the other observations differed slightly over the schools. The video data of week 6 were reviewed and content-coded. Of those video data we labelled the interactions on representation design, with and without a teacher present. An interaction was labelled when the participants were dealing with a drawing. That is, only when a drawing was mentioned, referred to, edited, or looked at for at least 5 s it was scored. If no interaction was found, we analysed earlier observations for those interactions on drawings. Table 2 lists the labelled interactions in the representation column. Next, by analysing the interviews with the students, we examined

Table 1 Categories and clues for drawings (from MacDonald and Gustafson 2004)

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

how the overall process had developed and whether the observations in week 6 were typical. Finally, the remaining observational data were reviewed to confirm whether the selected interaction was typical for the school or whether it contained critical incidents that might disconfirm typicality. The typical interaction and, if necessary, the critical incident(s) were used in the within-case and across-case analyses next to the categorised representations. For typical interactions the teacher's role was compared to Mercer's characteristics (2002, see p. 6 in this article). The students' final presentations were incorporated into the analyses. Table 2 shows an overview of observational video data and interactions on representations.

Results

In the analyses we discuss whether and how the student representations function as tools during the design and construction processes. The enactment of the intervention, that is the specific way the schools used the intended design and the guiding instrument, is reported here, since we regard those changes as results of our intervention.

For every school we describe how the intervention was enacted in general (within-school enactment). That is, how designing, constructing and, with regard to the controll schools, the prototype lessons were taught. Next, the role of representations and teacher guidance is discussed in the within-school enactment. Sample interactions on the role of representations and teacher guidance will be described. The overall pattern of each school's enactment is summarised first. In the across-school comparison we discuss how this description relates to the use of representations and disciplinary knowledge.

Table 2 Overview of video data from observations over time and the interactions over representations (repr.)

	School 1			School 2			School 3			School 4		
	Type	Duration	Repr.	Type	Duration	Repr.	Type	Duration	Repr.	Type	Duration	Repr.
Week 1												
Week 2												
Week 3	Practice	02:46:17	10	Practice	01:09:09	4	Practice	00:47:00	1			
							P-lesson	00:32:30	0			
Week 4										Practice (drawing)	01:0813	6
Week 5												
Week 6	Practice	01:09:15	2	Practice	01:53:05	3	Practice	01:03:52	0	Practice	01:46:46	7
Week 7										Practice	00:57:07	5
Week 8										P-lesson	00:31:21	1
Week 9							Practice	00:51:27	2			
Week 10				Practice	01:25:48	3				Practice	02:13:39	3
Week 11	Presentation (10)	00:49:00	2									
Later				Presentation (3)	00:52:05	3						
Total		04:44:32	14		05:20:07	13		03:14:49	3		06:37:06	19

At all schools we observed at least two practice lessons. At school 1 and 2 we observed also the school presentations and at 3 and 4 we also a prototype lesson (p-lesson)

Within-school enactment

School 1 (experimental)

Overall pattern Teachers in the practice workspace helped the students with practical problems, without explicitly referring to mathematics, science or other codified knowledge.

The school did not follow the provided guiding instrument. All the subgroups had to create a wire model of their tandem tricycle made to scale, as well as a drawing and a written plan before proceeding. Drawings were mostly made by hand. Subject matter teachers were sometimes present in the workspace, but did not integrate the practical assignment into their lessons. Vocational teachers assisted the students most of the time with practical issues of the design, stimulating the students to proceed and collaborate; for example how to propel the tricycle, which materials to use, etc. All subgroups had to present their products and processes to their peers and teachers.

In the week 6 observation analysis two instances of interactions on representations were found. Both were parts of a design issue that developed for more than half of the lesson. A vocational teacher helped a subgroup with finding the right way to create pedals from pieces of steel. The group-constructed tricycle had two front wheels and one rear wheel (see Fig. 3), which was an exceptional design (only two were found among the more than 25 tricycles constructed in all).

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

Excerpt 1.1

Teacher: [Whilst drawing]
The fixed part will be connected like this, right?
Then you'll have to make a little block for the axle to go through.
You need to connect it with two bolts
You see?
You can then put the axle in and move it around.

Later with the students and teacher by the frame:

Teacher: You see what I mean?
It can be welded onto this and the axle can run through it.

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

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

The representations present in the interaction analysed above were drawn by the teachers. Other representations (for example those made by student in week 3) were drawn by hand and functioned as draft designs. No subgroup created a reverse-engineered final representation.

Two interactions on representation were found in week 6. However, week 3 produced 10 (out of a total of 13 interactions over all observations, see Table 2). From that week's observation we learned that the students had to finish their drawings and plans in week 3 to

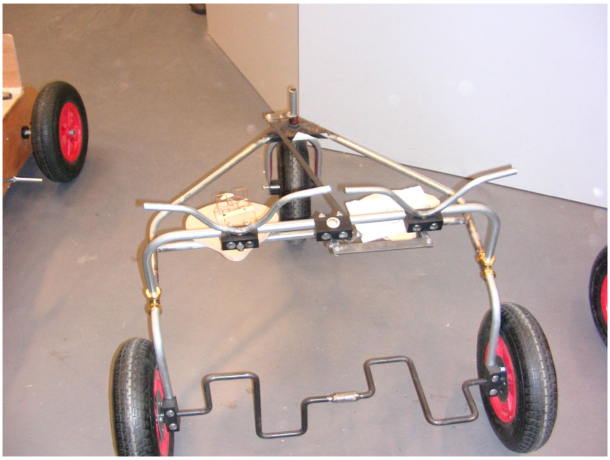

Fig. 3 Tandem tricycle with two front wheels from school 1 students

be allowed to continue with construction. From several interactions between teachers and students it was clear that the drawings required dimensions, scales and views from three angles. As one teacher said: 'Draw the dimensions, …, that's what I need. Then you are finished with the drawing.' One reference to mathematics by a practice teacher was heard during this week:

Excerpt 1.2

Teacher: [Standing at a work bench, whilst drawing and pointing to a scale model for the student]
… if this is 10 cm larger, it will be a little more than 10 cm larger, according to Pythagoras, but never mind that.
…

Teacher: You see that?
Student: Yes, about there?
Teacher: Then you can start with [constructing] the frame.
Student: Only that one then, then we can start with the frame. Cool.

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

Overall, at school 1 representations needed to be elaborated and moderately refined before students could proceed with the actual construction of the tandem tricycle. Once they were into the construction process the drawings and plans disappeared (after week 3) and only the teacher used drawings to help students with the practical issues. The drawings referred to in the interactions were therefore either initial sketches or elaborated drawings.

During peer presentations, students briefly reflected on their processes, while showing pictures and the final product. Two of the ten groups showed their design drawings, others mentioned them briefly, if at all. Hardly any questions were raised during the presentations.

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

Excerpt 1.3

Student The [tricycle] assignment is more fun. You are working on a product.
When you are working only on electricity, you are reluctant when you fail over and over again.
[with the tricycle assignment] you can't do anything wrong.
…
You can choose how and what to construct.

Two interviewed students said that drawing took up most of the time, because their first drawing had been rejected by the teacher. The drawing was done by hand and the students received assistance only from practice teachers.

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

School 2 (experimental)

Overall pattern The drawings and representations created by the students developed continuously from initial sketches to final drawings, and are used by the students themselves as well as by the teachers as tools on which to reflect.

The students at this school were in a combined stream called 'Comtech', which means that they were used to combining design, commercial insight and technical-practical assignments. All teachers in the team responsible for the group of students, regularly visited the Comtech classroom. During the project no special lessons were taught to the group as a whole. Some students receive specific skill training, or ad hoc instruction. Students used subject matter classes for their 'theoretical' problems. The content of the prototype lessons was taught ad hoc. Students used computers with 2D and 3D computer aided design (CAD) software for their drawings. The project ended with a peer presentation, in which the groups presented themselves as small companies, including production costs, price, processes and product marketing in their presentation.

In week 6 of their project drawings were lying around in the classroom. All together we counted three interactions on the representations involved. In one interaction, a student explains to his group how they should proceed with welding. Another subgroup first discusses construction issues behind the computer screen, with a paper drawing on the desk. Next, the group splits up and three of the members go to the metal classrooms, where they continue their construction. The student responsible for the drawing follows them later to bring the drawing. At the end of the lesson he draws on a piece of wood, explaining to the researcher that he is making a drawing so as to determine the angles for the pieces of steel that have to be sawn. He is using wood because the other students need the paper version of the drawing for their tasks. When the practice teacher suggests that he could calculate rather than measure the angles the student asks the teacher for help in the following exchange:

Excerpt 2.1

Teacher: I should not have to explain this
You have to go to the mathematics teacher for that
Student: He is not available
Teacher: Why don't you do it in AutoCAD
Student: AutoCAD does not work, otherwise I would have done it already.

Student walks out of the classroom and comes back. He is still busy measuring the angle of the pieces to be sawn.

Student Sir, I measured the angle and it was…[inaudible]
Teacher That's what I thought, because it was 60/30/30 [pointing at the angles of three of the complementary corners that make up the square]
Student Right, then you should have said so
Teacher Certainly not

The teacher takes the measuring tool from the table with the pieces of steel on it

Teacher When viewed from this angle, I see 60/30/30
Student Right
Teacher Now, this is what you have to learn to see.

The teacher goes on explaining tricks on how to see, and guess the angle.

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

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

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

Excerpt 2.2

Student: This time the dimensions were a problem.
We only saw that when the seats were being constructed.
We corrected that in the drawing.

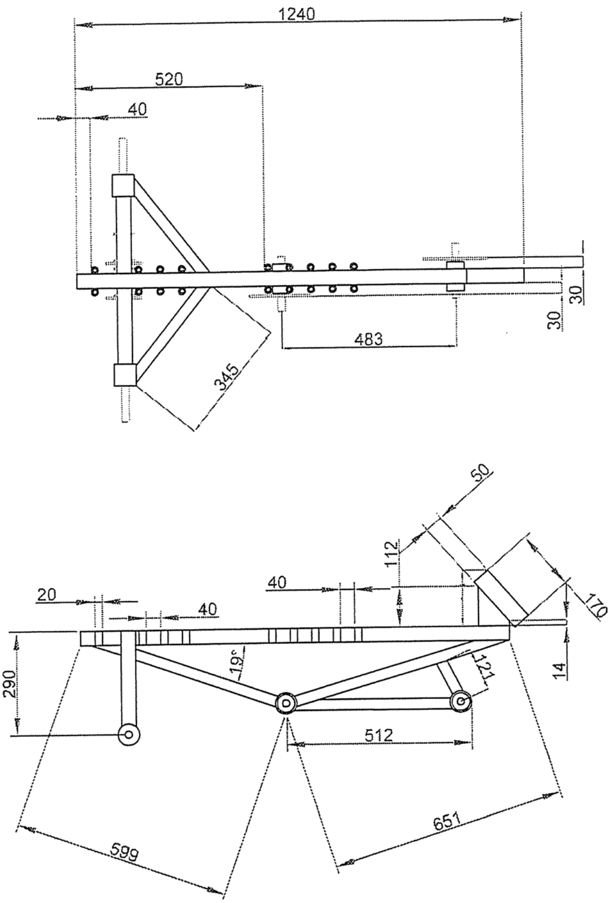

Fig. 4 Final drawing by school 2 students

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

Excerpt 2.3

Teacher: [A student] shows his problem to the mathematics teacher, comes up with a solution, and returns [to the Comtech classroom]

…

[In this project] this happened with all the groups. More often for some groups than others, though.

School 2 shows that the students work as small production companies for real clients. They design, calculate costs, construct and present as a team guided by several teachers.

The drawings created by the students develop continuously from initial sketches to final drawings and are used by the students themselves as well as by the teachers as tools on which to reflect.

School 3 (controll)

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

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

In week 6 no drawings were found in the observation. In week 3 drawings were still lying around, and only one interaction was found that referred to representations. In week 9 we found students drawing on the computer. It appeared that they were reverse-engineering their tricycle. Those drawings were made in the software programme 'Paint' rather than CAD. To enable possible further analysis we turned to the relevant week 3 interactions.

In week 3 a student comes to the practice teacher and asks an inaudible question. He holds a piece of paper in his hand with a picture of a bicycle on it, presumably from the Internet. The teacher tries to explain what the student's plan (which includes the possibility of having two children steer the tricycle) means for the construction design.

Excerpt 3.1

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

Student: Really?

[They walk to a metal model of a crane]

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

The example above is typical of the way students in the workshop were guided mainly in their practical constructions. Practical tips and solutions were provided and skills were demonstrated. As already mentioned, hardly any interactions on representations were found, neither in the other observations nor in the prototype lesson. In no other observations than in week 9 were students found behind the computer reverse-engineering their construction drawings. Even at that final stage drawings were still initial sketches.

In an interview with two students during the project, they first pointed out that the difference between the tricycle assignment and the usual assignments was the time available. Normally an assignment took 2–3 weeks. They also confirmed our observations that no assistance was provided by mathematics or physics teachers. The help offered was in the workshop during practice hours.

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

Excerpt 3.2

Teacher: Paying more attention to mathematics and physics by means of the project did not work out. Although there was some drawing done in AutoCAD …
the drawings were not usable … without dimensions and so on. Those are between their [students'] ears.

At this school, especially during the construction stage, we did not find any examples of the explicit use of concepts, mathematics or physics. There was hardly any connection with theory as expressed in curriculum subjects. The prototype lesson could be characterised as an introduction to the practical problems of tricycle construction and the only drawings used as reference were an Internet and the initial computer sketch.

School 4 (controll)

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

In comparison to the other schools the students appeared to spend more time on designing. In project week 7 they were found behind computers trying to find the optimal transmission or wheels, whereas at other schools this was not observed after week 6. Prototype lessons (three out of five) were taught separately to the whole group. The practice teacher at this school took on a role different from his usual one as a welding teacher. Since his background was in mathematics and science he took the lead in the project. He taught three of the five advised prototype lessons and guided the students during the construction together with one other teacher.

At school 4 we found seven interactions on drawings in week 6. Many of those were rather short, while the drawings were examined without any discussion. What we would like to discuss here is an interaction on a drawing of which we know how it came into existence through the discussion between the subgroup members recorded in the observation of week 4. In that week the subgroup was engaged in a discussion on whether or not they would construct a tandem that could be transformed into two separate bicycles if desired. The problem was how the second bicycle could be steered separately while also having a fixed set of handlebars when connected as a tandem. When this argument was solved, it was decided that the group would construct a detachable tandem (see Fig. 5), which was exceptional since no other group had designed a tricycle of that type. As a result two practically identical bicycles needed to be constructed. The week 6 interaction is about this particular design (see Fig. 6).

Excerpt 4.1

Teacher: What is this length [pointing to the drawing]

Students: [inaudible]
400?
40 cm.
And this one? Have you switched that off [a function in the CAD software]
Or, you could make this 45 too and this 55
…
[students bend the tube and go back to the drawing to check how to saw off tube ends]

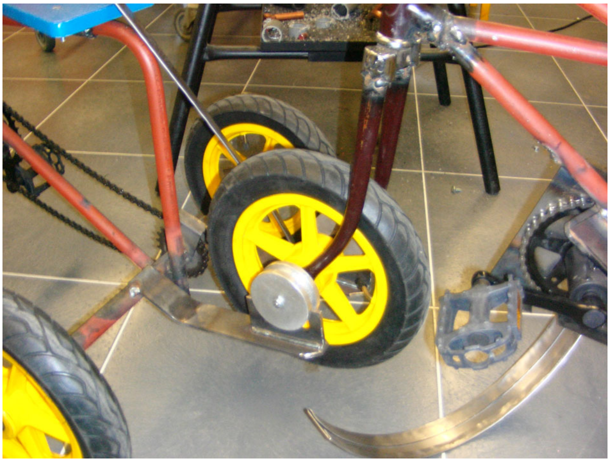

Fig. 5 Connection between bicycles of a two-part detachable tandem at school 4

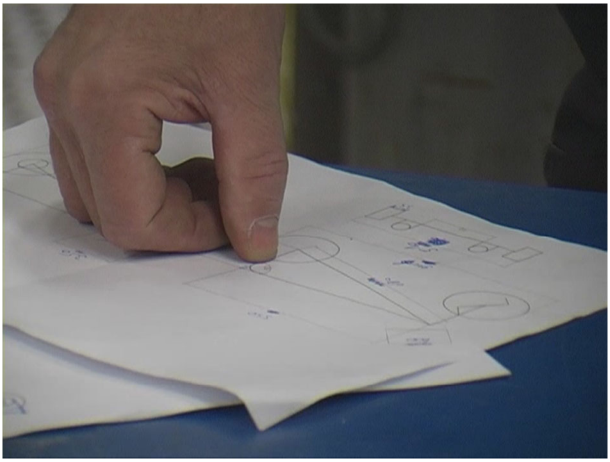

Fig. 6 Elaborated drawing by students at school 4 to which the teacher refers

Teacher: Which part should be 40? Take your drawing.
Here you put 40, but is that 40 on the top or,…
Student That's on the top.

The interaction continues on how to saw off tube parts.

The teacher uses the drawing to help the students with their problem of bending and sawing the frame tubes. He refers to the drawing and not only tries to find out what the students' plans are, but also notes that the drawing is not clear to him. In other words, he uses the drawing and reflects on it as a tool for communication.

In the observed prototype lesson the teacher explores the transmission problem with the students. By drawing a representation of a transmission on the blackboard he relates the practical issue of construction to the more theoretical concepts of transmission, speed and ratio. By asking the students questions he tries to make them think of possible gearwheel combinations and their consequences. He follows that up with other examples such as the number of revolutions on a lathe.

Excerpt 4.2
Teacher: Do I need a small [gearwheel] in front and large one at the rear? Or the other way around?

A student responds inaudible

Teacher: Say small in front, large at the rear, then what happens?
…
Let's put some figures on it
…
Now, what is the number of revolutions for the front wheel per minute?
How fast will the tricycle move?
First I need a calculation, a formula.
…
[Students respond and arrive at the point where they need to know the circumference of the wheel]
That's maths: how do I calculate the circumference of a circle?
[The instruction continues with the speed of the tricycle and the number of lathe revolutions]

Eight drawings were found in all the observations, of which three were initial sketches observed in week 4, three were elaborated and refined drawings in week 6, and two were other drawings (for instance one on the internet as an example or a short online game). No final or presentation drawings were found. However, the representation did not actually disappear after they were created. They were still used in week 7 during construction.

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

The teacher confirmed the students' statements. He said that the only 'theory' students usually get in practice is reading construction drawings. On the tricycle assignment he thought the students learned mathematics and physics, "because they realise that it is useful [with regard to constructing the tricycle]."

At school 4 the elaborated drawings remained present during the construction stage of the project, with teachers referring to them when they helped students with practical problems, such as bending a tube to the correct angle. The observed prototype lesson focused explicitly on the mathematics and physics concepts behind the transmission of a tandem. The teacher provided the representations in a ready-made fashion. Working in groups and designing themselves were new activities for the students.

Across-school comparison

In the across-school comparison we are interested in how the overall process at all schools can be characterised and to what extent schools differ in their enactments.

First, week 6 observations confirm the experiences from earlier studies to the effect that at that stage in the process at three of the four schools the students are in fact in between designing and construction. The video data show that the frames of most tricycles are finished and students are connecting the other parts to it. At Schools 1 and 3 wheels are already connected and students are playing with the tricycles. Except for one school (school 3), drawings are still present in the workplace. At schools 2 and 4 the representations are explicitly referred to and used as tools for communication and orientation. At school 2 this reference is used not only to solve the practical problem but also as an example to refer to the academic discipline of mathematics: how to calculate and estimate angles (see Excerpt 2.1). The orientation goes beyond the actual construction towards the formulation of a strategy.

Secondly, it seems that the construction is now the main object of the students' activities, from week 6 onwards. All interactions are about what to do how in construction. The teachers have to help with practical problems, such as where to find tools or how to adjust the machines. At school 1 this is already the case in week 3, when construction drawings and plans have to be finished.

Table 3 shows that at school 2 all subgroups (four) had final presentation drawings. Although some students at school 1 use their drawings during presentation, they do not reflect on the drawing itself or use it as a tool to explain their process. At no other school were final drawings found. At school 3 apart from one initial sketch no drawings were observed. Apparently, the design process continued until the end of the project only at school 2, while drawings were also used as tools for communication.

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

Table 3 Drawings in observations during the process

	School 1	School 2	School 3	School 4
n	33	16	23	15
Total drawings	12	12	2	8
Initial drawings	5	0	1	3
Elaborate drawings	3	7	0	3
Final drawings	1	4	0	0
Other	3	1	1	2

The number of models may be less than the number of interactions over models, since one model can appear in more than one interaction

Conclusion and discussion

In this article we argue in favour of the design and use of representations as a core activity during practical classes to improve students' understandings. In addition, integration was envisaged between practical skills and content knowledge in mathematics and science. Qualitative data from interventions at four schools were analysed in order to find key determinants that might relate student's deeper understanding of codified knowledge and designing and using representations in the school workshops. For this purpose we used the data of the latest experimental intervention to conduct a qualitative analysis. The main conclusion from previous quantitative analyses in the same research project was that no difference between the schools as defined by the designed conditions could be found (for a presentation of the quantitative outcomes see Van Schaik et al. 2010a, b). For the present article we aimed, first, at finding out in general the ways in which the research designs were implemented at every school. Our next goal was to establish how the use of representations developed micro-genetically within a process of tandem tricycle construction, and whether it was effective in joining experience and general knowledge, as codified in the general curriculum. In view of the above aims, our two research questions were the following:

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

From analyses of the within-school enactment and from across-school comparisons it is clear that two schools stand out in the way representations are used in their practice workshops. Each school could be characterised by a unique, overall interaction pattern. In the present section we will elaborate—and reflect on—these patterns in the light of our theoretical assumptions on using representations. At schools 2 and 4 the representations remained visible and continued to be used until the end of the process, whereas at schools 1 and 3 the representations against all intents and purposes disappeared once the actual construction of the tandem tricycle had begun. The conclusion is that the use of representations at schools 2 and 4 resembles the practice of professional designers more accurately than at schools 1 and 3 (MacDonald and Gustafson 2004). In a way the teachers at those schools do what Roth (1996) proposes: they support

> […] participation in culturally organized activities and environments in which this knowledge plays a role; that is, activities where students experience these canonical forms of knowledge used by someone who already has a certain degree of competence (p. 163).

Moreover, at schools 2 and 4 more interactions on representations were found in the observations. Teachers and students used their representations as tools for orientation and detailed communication about the object to be designed and constructed. The first was observed for example when students at school 4 discussed whether or not to design a tandem that could also be dismantled into two separate bicycles (see Fig. 5). At school 2 students communicated by means of representations when they tried to find solutions to practical problems, for example in determining the correct angle for sawing off tube ends (e.g. Excerpt 2.1). They updated their drawings when the design changed during the construction process. This updating could be viewed as a way to establish their collective memory and use the representation as a tool for communication at later moments in time, with themselves or their peers (see Excerpt 2.2). Although interactions on representations were also observed at school 1 (not at school 3), the teacher at that school regarded the students' drawings as tasks to be finished before actual construction could start. Hence, the students' drawings were checked on certain points, after which they were discarded. Teachers only used their own representations to help students with practical problems. The answer to our first research question is therefore that at school 2 and 4, as opposed to school 1 and 3, the drawings were actual tools in the design process and remained visible until the end of the project. Put differently, the community of practice at those schools simulated the design practice of professionals best. Therefore, the boundary between the simulated and the actual workplace might be bridged more easily by the students.

With regard to students' understanding of the disciplines, we are led to the conclusion that at school 2 the vocational discipline of (technical) designing was the main goal. Students continued designing and created a final presentation drawing on which they reflected during a presentation to peers and teachers. At school 4 the academic disciplines of mathematics and physics were given explicit attention during the process, with the teacher teaching the appropriate content during the prototype lessons. At the two other schools there were few signs of attention to academic disciplines during workshop practice.

The drawing of construction models as a means of constructing a tricycle at schools 2 and 4 was not merely a goal in itself during the design and construction process. Teachers at both schools explicitly pointed out the function of representations to the students. Sometimes representations were used to find solutions to practical problems (e.g. the correct way of bending a tube to the right angle), while at other times the teacher used representations to refer to mathematical rules (e.g. calculating or estimating angles in a drawing). We conclude therefore that at those schools the design and use of representations was integrated into the overall design process, from draft to finished product. As a result the role and function of representations could be understood by the students by 'perspective taking': the understanding and the perspective of a concept or problem became explicit, and could be enhanced by collectively reflecting on representations (Akkerman and Bakker 2011b).

The teaching strategy at school 2 resembled best that of guided co-construction. The students collaboratively reconstructed models through an on-going and reciprocally discursive process, focused on the solution of task-related problems. However the knowledge codified in the subject curriculum was only indirectly referred to. At school 4 on other the hand, codified knowledge was taught in a providing way, resembling direct instruction.

Since it is the teacher's role to' … maintain connections between the curriculum-based goals of activity and a learner's existing knowledge, capabilities and motivations' (Mercer 2002, p. 143), the question remains how codified knowledge is best instilled. We suggest that discussions about unguided or minimally guided or direct instruction (Kirschner et al. 2006) should be supplemented with detailed descriptions of teacher activities when they relate to students' (discursive or practical) activity. In our view, then, further research is required to explore teaching/learning strategies that incorporate the practices of schools such as schools 2 and 4.

The present study explored an intervention at four schools, using qualitative data. A next step could be to conduct a meta-analysis on the data of the entire design-based research project, incorporating data from the first case study plus the two interventions. This would enable a more accurate definition of the optimal teaching/learning strategy, which could subsequently be used in a larger scale follow-up design experiment.

On the basis of the present data the conclusion is warranted that the integrated use of representations is potentially capable of enriching practical assignments with theoretical concepts from mathematics and science. Such enrichment presumably contributes to the formation of disciplined perception. We conclude that designing and using representations as a core activity in vocational education could be the key to integrating theory into the workshop. Moreover, our observation provided ground for speculation about the formation of disciplined perception in students that is about conceiving problem situations analytically like professionals. It is not too far-fetched to see the use of representations as tools for orientation and communication, as manifestations of such disciplined perception. Schools 2 and 4 seemed most advanced in stimulating this way of addressing problem situations in students. This is in line with previous research that using representations, or models, in education in a guided co-constructive way supports deep understanding (Terwel et al. 2009; Van Dijk et al. 2003; Terwel et al. 2011). Solving problems using representations as tools for communication and orientation during education and training might therefore be a way to connect actual (design) practice to more general learning and development. We suggest that further systematic research be devoted to this problem in greater detail.

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